# FIELD OBSERVATIONS OF WAVE RUNUP ON A SAND BEACH

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RUNUP ON A SAND BEACH

by

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# ABSTRACT

Six sets of field measurements of runup resulting from both wind waves and swell were made on a uniform sand beach. Waves were recorded simultaneously directly offshore at a point outside the surf zone. Each individual runup was correlated with a specific wave, using a travel-time plot. Runup occurrences were always found to be fewer in number than wave occurrences, particularly when wind waves were present. Large variations in the runup resulting from waves of a given height were found to exist. These variations in height and ratio of runup to waves were caused in large part by the interaction of successive foam lines. Interaction occurred in the form of retardation by backwash of preceding waves, overtaking by a following foam line, and overriding by a small unbroken wave. It is concluded that the complicated nature of runup resulting from ordinary sea and swell makes it difficult to predict runup accurately from laboratory studies.

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## ACKNOWLEDGEMENTS

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## 1. Introduction

The objective of this study was to observe and record individual runup occurrences on a sand beach, and to investigate the relationship between the runup values and wave properties determined at a point outside the surf zone.

Runup is defined as the vertical height above still water level of the uppermost extent of a wave washing up a beach slope. Some of the most interesting effects of water waves occur when rotational waves approach a shore, pass through the surf zone as translational waves, and surge up on a beach. These are also some of the least studied aspects of waves. One reason for this is that no general theory now exists that describes waves propagating in deep water, entering shallow water, breaking in the surf zone, and finally moving up a beach slope. The turbulent areas associated with the surf zone are particularly difficult to approximate with mathematical models and to study in the natural environment.

For practical reasons, most runup studies have concentrated on the special case of impulsively generated waves. Keller (1964), while investigating tsunami waves, devised a numerical method to solve an initial boundary value problem for the equations of the non-linear shallow-water theory. Later, Keller (1965) improved the numerical method and developed an analytical theory of wave breaking and bore formation and growth on a uniformly sloping beach. Le Méhauté (1964) investigated the properties of waves generated by an underwater nuclear explosion. He presented a set of theories, computing methods, and results for the propagation of these waves on a slope and the resulting runup. Later, Le Méhauté (1966) conducted wave-tank experiments and

compared the results with his theories. Extensive theoretical and experimental runup studies have been conducted by Van Dorn. Working with a wave channel at the Scripps Institution of Oceanography, Van Dorn (1966) used empirical results to construct a complicated nomograph from which runup predictions can be made. Wiegel (1964) has reproduced several empirical curves constructed from laboratory runup studies conducted prior to 1960.

Almost all research has considered runup associated with either a solitary wave or a series of periodic waves. In no theory or laboratory experiment dealing with wave motion and runup has any provision been made for the complex nature of real ocean waves. Although field observations have been made of the runup of impulsively generated waves, no studies are known to have been made of runup resulting from ordinary sea and swell. This study has been conducted with the goal of investigating the runup of these waves.

## 2. Data Collection and Reduction

The location selected for observing runup was Del Monte Beach, situated at the sheltered southern end of Monterey Bay. Because of the shape of the bottom contours offshore, nearly all waves approaching this beach are subjected to considerable refraction. This results in much reduction of the wave height and also has the effect of causing all waves to approach the beach with crests parallel or nearly parallel to the shoreline. For several hundred meters or more on either side of the observation point, the beach and the area immediately off the beach have a uniform gentle slope seaward. The inclination of the beach face was approximately 1 in 25 while the field studies were being conducted. The beach is firm medium-grained sand, well sorted, and of quartz, quartzite, and felspar composition.

A line of 20 rails, against which the beach profile can be measured, has been driven into the beach face. The rails extend from about the level of Mean Lower Low Water (MLLW) to the rear of the beach at intervals of approximately three meters. The position and elevation of each rail was accurately determined, and during each set of observations the height of the beach face above MLLW at each rail was measured. During a given set of observations, the runup of individual waves was recorded in terms of the horizontal distance reached, as measured along the line of rails. These values were converted to vertical runup values using the beach profile, as described later.

Simultaneously with the runup observations, waves were recorded offshore using a Snodgrass Mark IX pressure-type wave sensor. The instrument was installed about 200 meters directly seaward of the rails, and connected to a recorder located in a building behind the beach. The

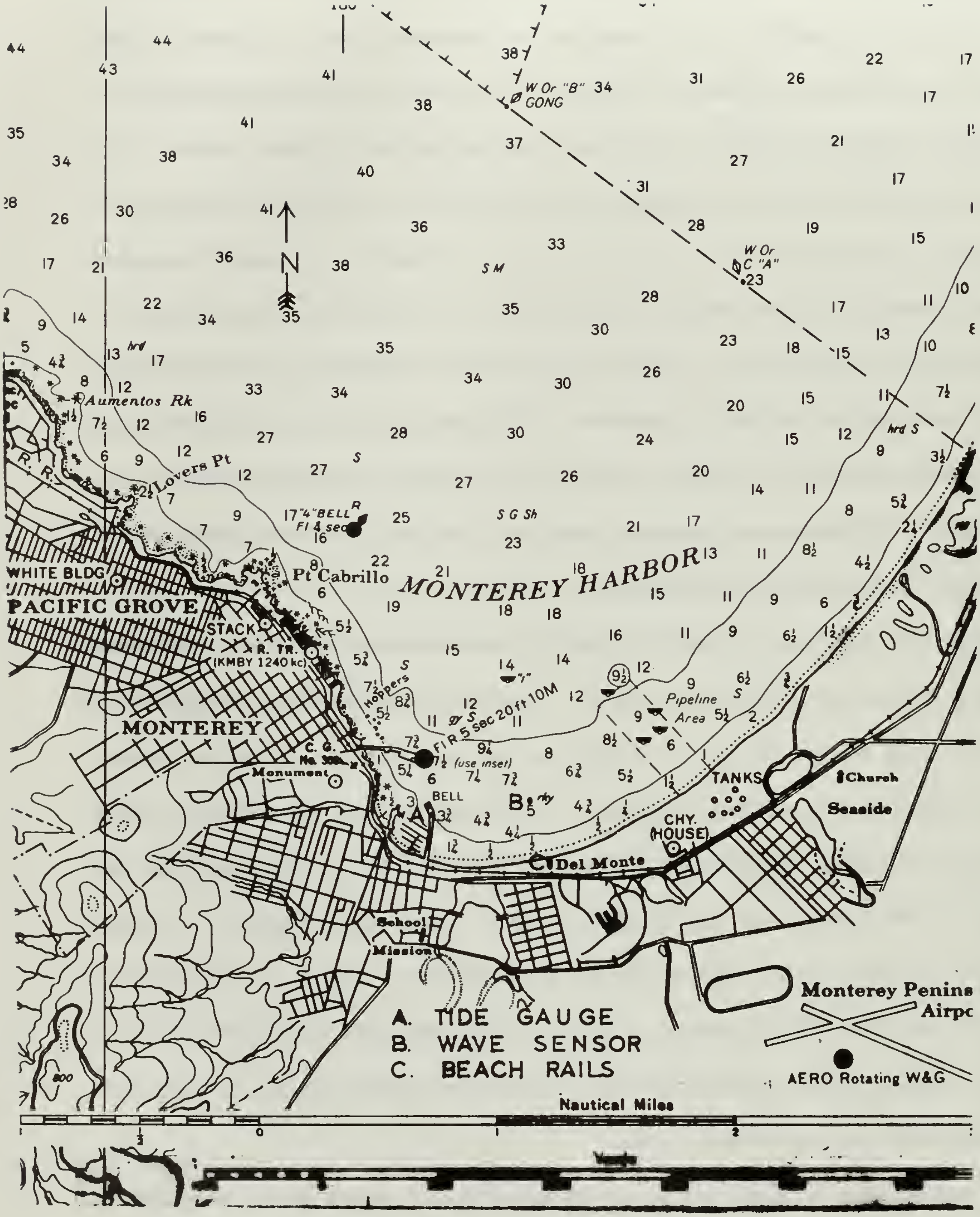


FIGURE 1. SOUTHERN END OF MONTEREY BAY

pressure sensor was one meter off the bottom in a water depth of approximately eight meters below MLLW.

At the beginning of a given set of runup observations, a timing watch was started and a precise time mark was placed on the wave record. Then, a set of beach observations was made in which the time and location of the maximum shoreward position reached by each successive foam line along the rail line was recorded, together with any irregularities of the surf noted by the observer. The position of maximum runup was recorded in terms of rail number and tenths of the distance to the next rail. At the completion of each series of observations a second time mark was placed on the wave record.

Because of the uniform nature of the beach, the line of maximum runup, or swash line, of a given wave generally extended for several hundred meters in each direction from the rails with little deviation. The lateral uniformity of the swash line justified measurement of runup at a single location along the beach, that is, along the rail line. The rails themselves had no noticeable effect on the runup.

Six sets of field observations were made and are summarized in Table I. All observations were made under similar conditions of water level (low tide) and beach profile. Figure 2 shows the beach profiles existing during each run.

The sea conditions prevailing during each observation period are summarized in Table II. On three days the wave pattern was mostly swell. Wind waves were predominant on two other days. On the sixth day there was a combination of wind waves superimposed on large swell, which occurred in well-defined groups. All waves approached the beach with crests parallel to the shoreline. Breakers observed were all of the

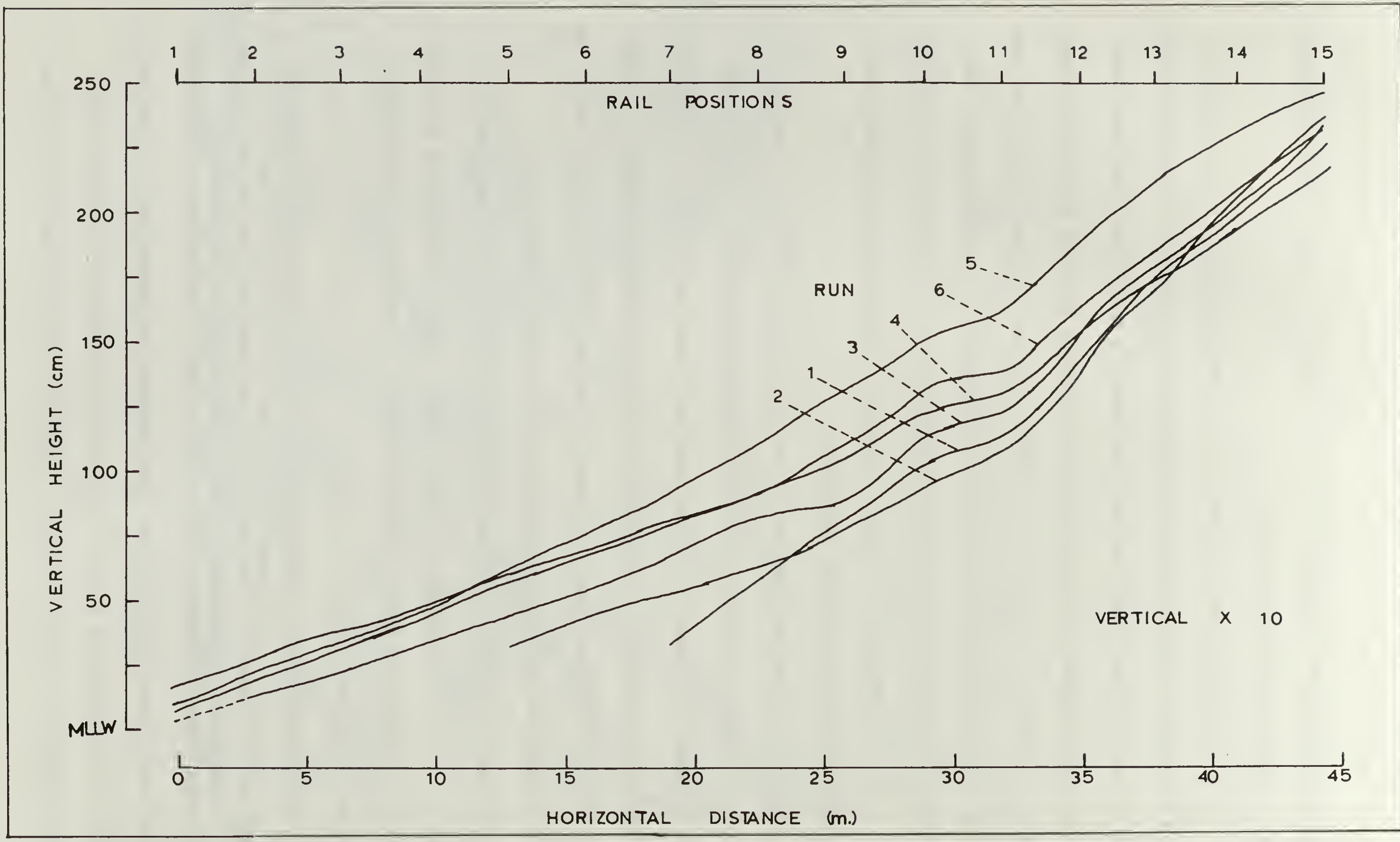


FIGURE 2: BEACH PROFILES

TABLE I: SUMMARY OF OBSERVATIONS

| Run | Date | Duration | Number of Runup Values Recorded | Mean Still Water Level Above MLLW |
|---|---|---|---|---|
| 1 | 15 Feb | 17.5 min | 75 | 0.64 meters |
| 2 | 17 Feb | 32.5 | 118 | 0.62 |
| 3 | 19 Feb | 17.0 | 62 | 0.32 |
| 4 | 3 Mar | 31.0 | 132 | 0.97 |
| 5 | 29 Mar | 22.0 | 105 | 0.98 |
| 6 | 31 Mar | 47.0 | 180 | 0.27 |

plunging type. Wind speeds were estimated, and the wind, when present, blew directly onshore.

Table II shows, as expected, that the average periods of the wind waves were notably shorter than those of the other waves. The significant wave heights (the average of the highest third of the waves) are given for the waves at the location of the wave sensor, and are corrected for the bottom pressure effect based on the average wave periods. The range of significant heights was small with the exception of the relatively large value of Run 6. The initial steepness ($H_o'/T^2$) of each wave train was computed using the unrefracted deep-water wave height ($H_o'$), determined from the significant height at the sensor location, and the average period (T). The data indicate that the swell had long low profiles while the profiles of the wind waves were somewhat steeper. The relatively steeper profile of the final run is attributed to the presence of wind waves superimposed on the swell.

In order to compare all runup and wave data it was necessary to establish a common water-level to which the measurements could be referred.

TABLE II: SUMMARY OF WAVE CONDITIONS

| Run | Date | Average Wave Period (T) | Significant Wave Height at Sensor (H) (1) | Significant Height of Unrefracted Deep-Water Waves ($H_o'$) | Initial Wave Steepness ($H_o'/T^2$) | Remarks |
|---|---|---|---|---|---|---|
| 1 | 15 Feb | 12.4 sec | 1.34 ft | 1.21 ft | .0079 | Swell, Wind calm. |
| 2 | 17 Feb | 15.0 | 1.23 | 0.92 | .0038 | Swell, Wind calm. |
| 3 | 19 Feb | 14.0 | 2.09 | 1.79 | .0092 | Swell, Wind calm. |
| 4 | 3 Mar | 10.4 | 1.72 | 1.63 | .0138 | Wind waves, Wind about 10 knots. |
| 5 | 29 Mar | 9.4 | 1.95 | 1.95 | .0221 | Wind waves, Wind about 20 knots. |
| 6 | 31 Mar | 13.3 | 4.04 | 3.56 | .0202 | Mixed waves, Well-defined groups, Wind about 25 knots. |

(1) Corrected for hydrodynamic damping.

Since runup is defined in terms of vertical height above the still water level, the reference adopted for both the runup and wave measurements made during each run was the mean still water level (MSWL) prevailing during that run.

The runup values, recorded on the beach in terms of horizontal extent, were first converted to vertical heights relative to MLLW using the beach-profile measurements for each run. The elevation of MSWL above MLLW was determined from tide data for five-minute intervals during each observation period by examining the marigrams from the standard recording tide gauge installed on Wharf No. 2 at Monterey Harbor, about 1000 meters from the runup observation point. Applying these elevation differences, the runup distances were then converted to vertical heights relative to MSWL. A schematic diagram showing the relationship between the reference levels, and the locations of the wave sensor and beach profile, is presented in Figure 3.

The wave records were analyzed assuming that the centerline of the record represents the MSWL. Periodic instrument checks during near-calm conditions showed this to be a valid assumption, as the trace coincided with the record centerline. The elevation of every wave crest in a given run was recorded relative to the centerline, along with the time the crest appeared on the record. Some crests were below the record centerline, and in these cases a negative elevation was recorded. This unconventional procedure of including negative crests in the tabulation of individual waves for each run was followed because it was found that individual runup occurrences were associated with them, as well as with larger waves. Because of this, the term wave-crest elevation has been used throughout the study rather than wave height. This measurement

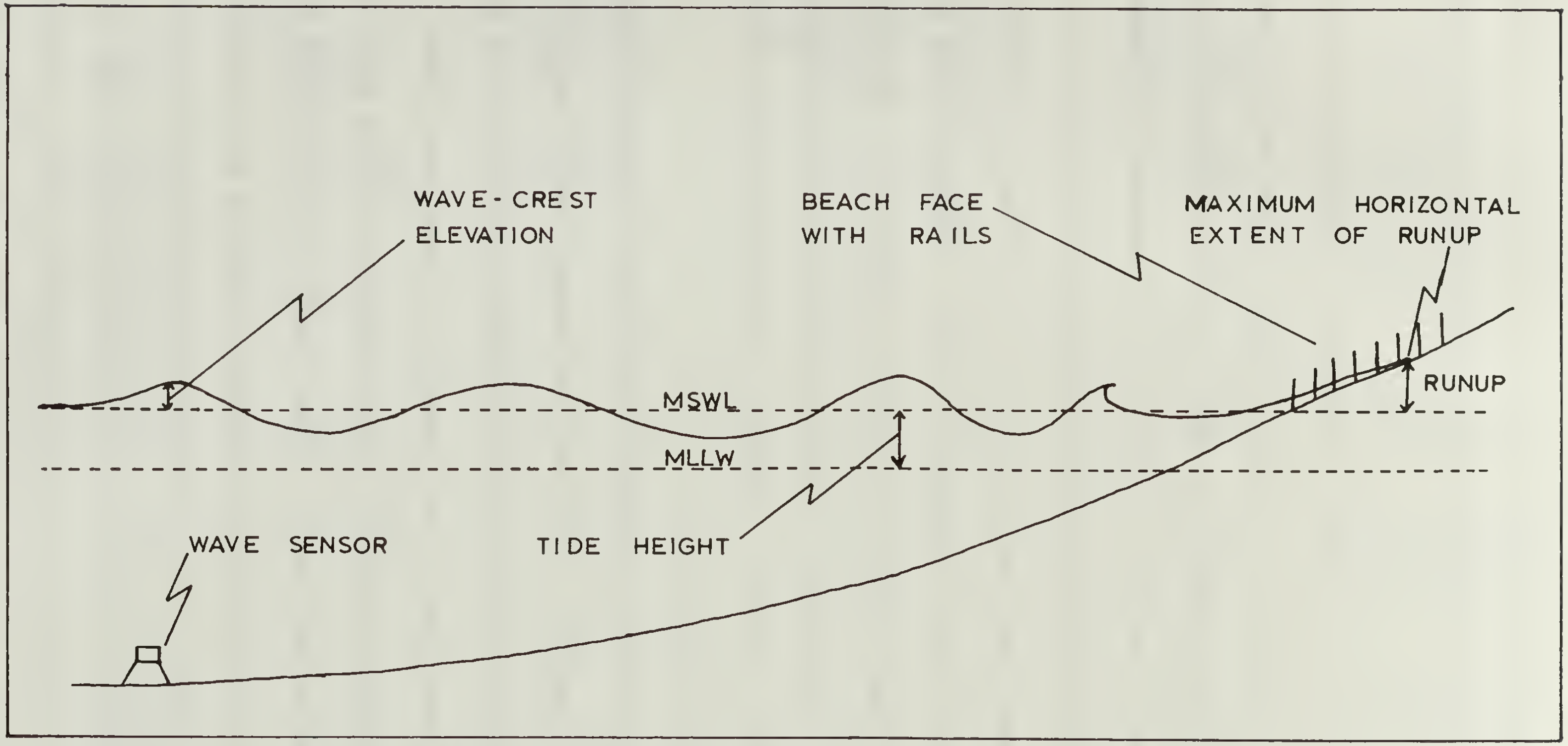


FIGURE 3. REFERENCE LEVELS

would be equivalent to the wave amplitude, or one-half the wave height, in a series of periodic waves. The waves observed were not regular, of course; however, the wave-crest elevations generally were very close to the apparent wave amplitude.

The units used for crest elevation are wave-recorder units (w.r. units), which are based on the divisions printed on the wave record. Each wave-recorder unit, uncorrected for the bottom pressure effect, is equal to 4.57 centimeters. These units were used for convenience for comparing relative wave sizes. If corrected for hydrodynamic damping, a wave having a period of 13.4 seconds would have an amplitude at the surface over the wave sensor of 5 centimeters for each recorder unit, or a wave height of 10 centimeters per recorder unit. This conversion factor varies slightly for waves of other periods, but is a good approximation for use in mentally converting wave-crest elevations in wave-recorder units to wave heights at the surface in centimeters.

Correction of the recorded individual wave-crest elevations for bottom pressure effect would have been desirable, but was not feasible because the correction is dependent on the wave period, and the varying time intervals observed between individual waves are probably not equivalent to the periods of the component wave trains. Similarly, individual wave heights recorded at the sensor location cannot be converted with certainty to deep-water heights or to breaker heights, because these conversions also probably are dependent on component wave period.

Throughout this study, when considering individual waves, the time between the passage of successive crests is referred to as wave interval rather than wave period. In a complex wave train in which there are widely varying intervals, period is used only to express the statistical

average for the train, and would be misleading if applied to individual waves.

A possible source of error in both the runup and the offshore wave data is the use of MSWL as the basic reference for making all measurements. The concept of still water level is hypothetical, as the ocean surface is neither still nor level at any time. In addition to ordinary sea and swell, long waves having periods in the ranges of 1-2 minutes and 20-30 minutes are known to occur commonly in Monterey Bay (Raines, 1967). These long waves can be seen on the tide records. No water-level measurements were made in the surf zone during this study, therefore no method was available to determine the level of the fluctuating water surface during a given run. It is believed, however, that the errors introduced by the use of MSWL are small and do not alter the basic results.

The wave-crest elevations and the runup values for all observation periods are tabulated in the Appendix.

### 3. Statistical Properties of Offshore Waves and Runup

#### a. Interval Distributions

The frequency distributions of wave intervals and runup intervals for all six runs are shown in the histograms and cumulative curves in Figures 4a through 4f. Figure 4g is a composite of the cumulative curves of the previous figures. The properties of the interval distributions are summarized in Table III.

During each of the six observation periods, the number of waves recorded offshore exceeded the number of runup occurrences. The ratio of runup occurrences to number of waves was clearly lower on days with wind waves than on days of swell, indicating that with wind waves there were a large number of cases where two or more waves combined to produce one runup. The median wave intervals were notably shorter for wind waves than for swell, as would be expected. However, the median runup intervals were nearly the same for all runs, and were only slightly shorter on days of wind waves. This indicates that the runup intervals were dependent upon factors other than wave intervals alone. It is likely that the character of the waves and the beach slope have important effects on runup intervals.

The ranges listed in Table III for both the wave and the runup intervals are the differences between the 10th and 90th percentiles. The choice of these limits eliminates the small number of unusually long and short intervals. Runs 4 and 6 had relatively narrow wave-interval ranges, while the other runs had broader ranges. The runup-interval ranges were notably larger during wind-wave conditions than during swell. The reason for this is that with wind waves there are more instances of two or more waves of short intervals combining to produce one runup

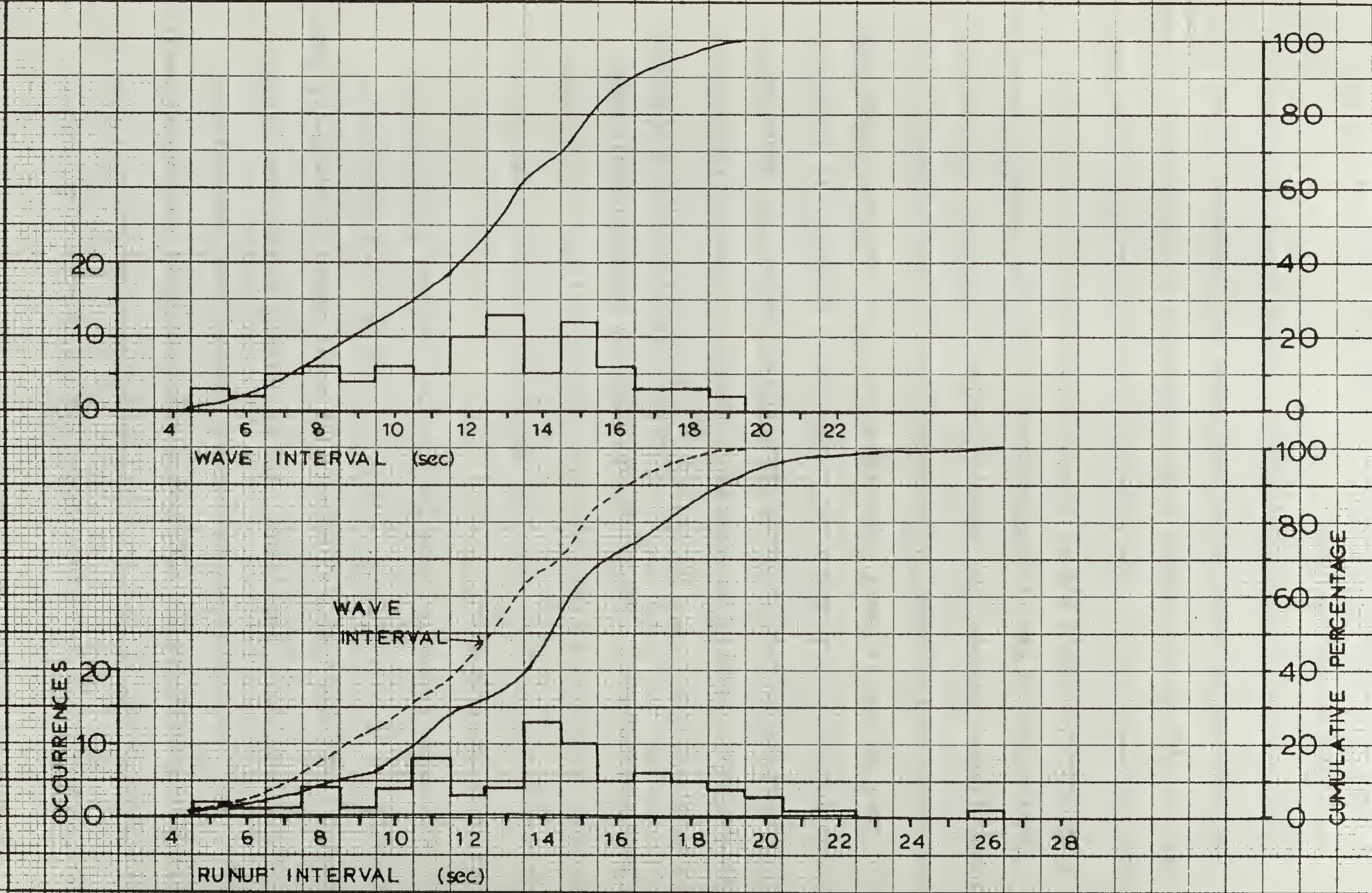


FIGURE 4a INTERVAL DISTRIBUTIONS RUN 1

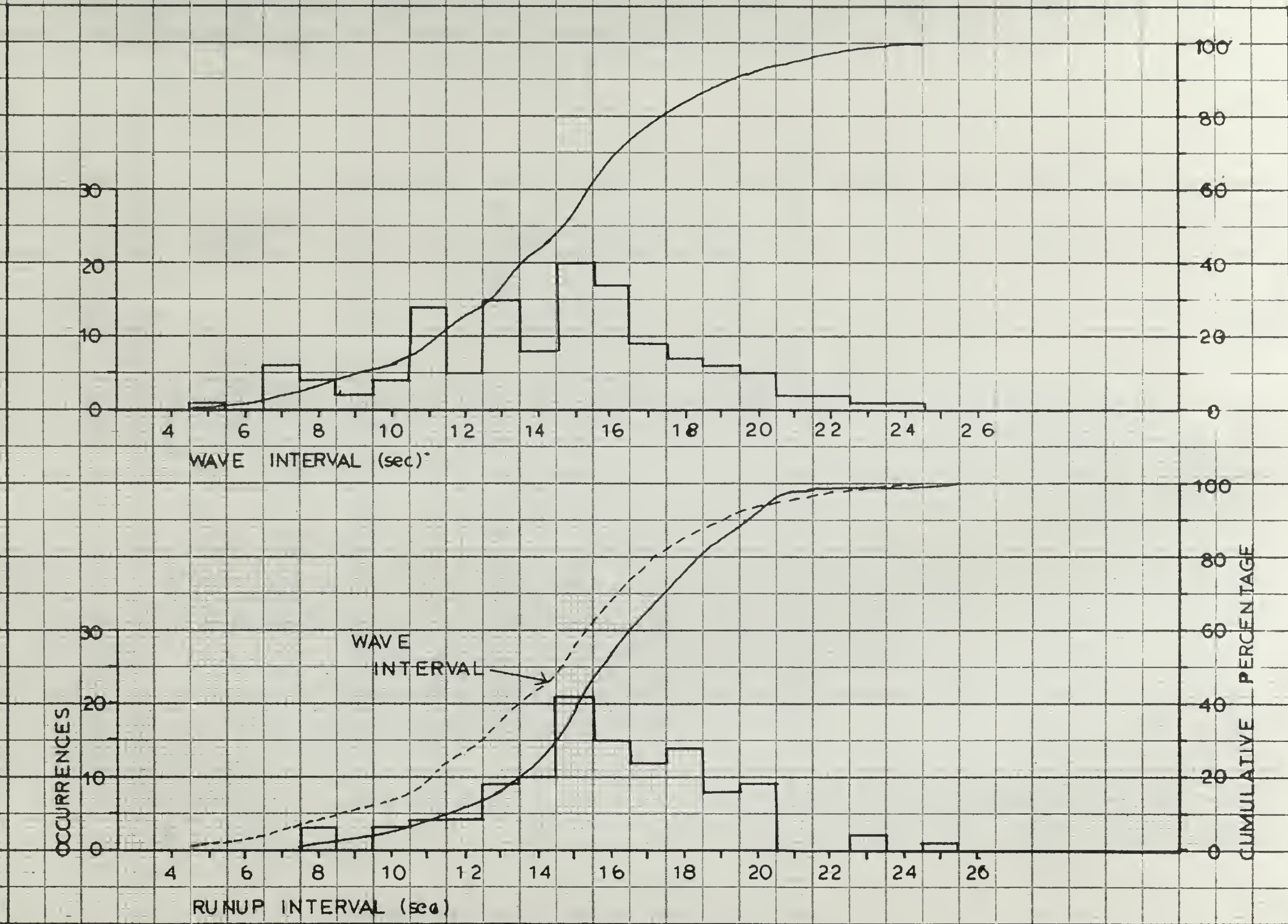


FIGURE 4b. INTERVAL DISTRIBUTIONS: RUN 2

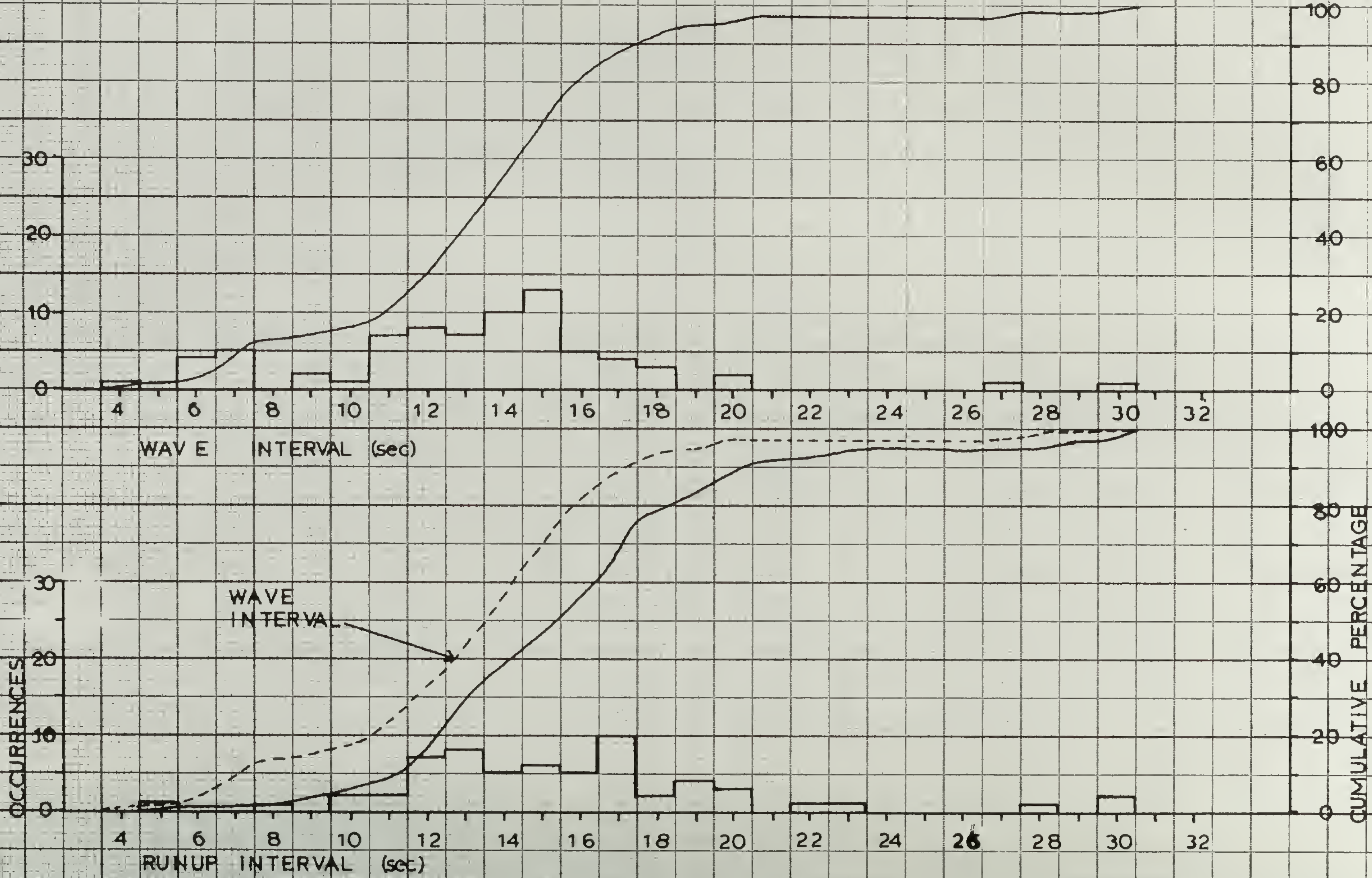


FIGURE 4c. INTERVAL DISTRIBUTIONS: RUN 3

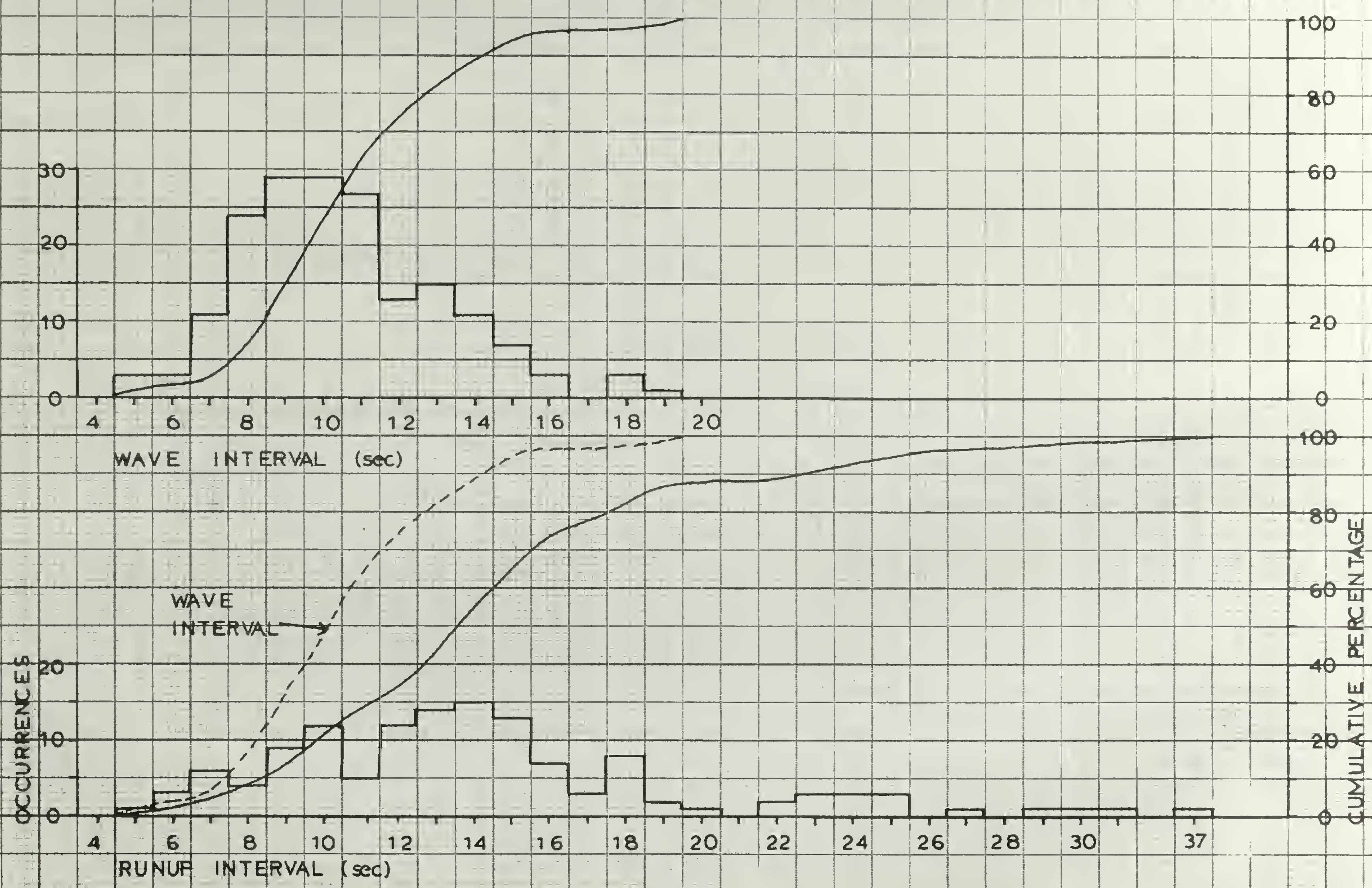


FIGURE 4d. INTERVAL DISTRIBUTIONS: RUN 4

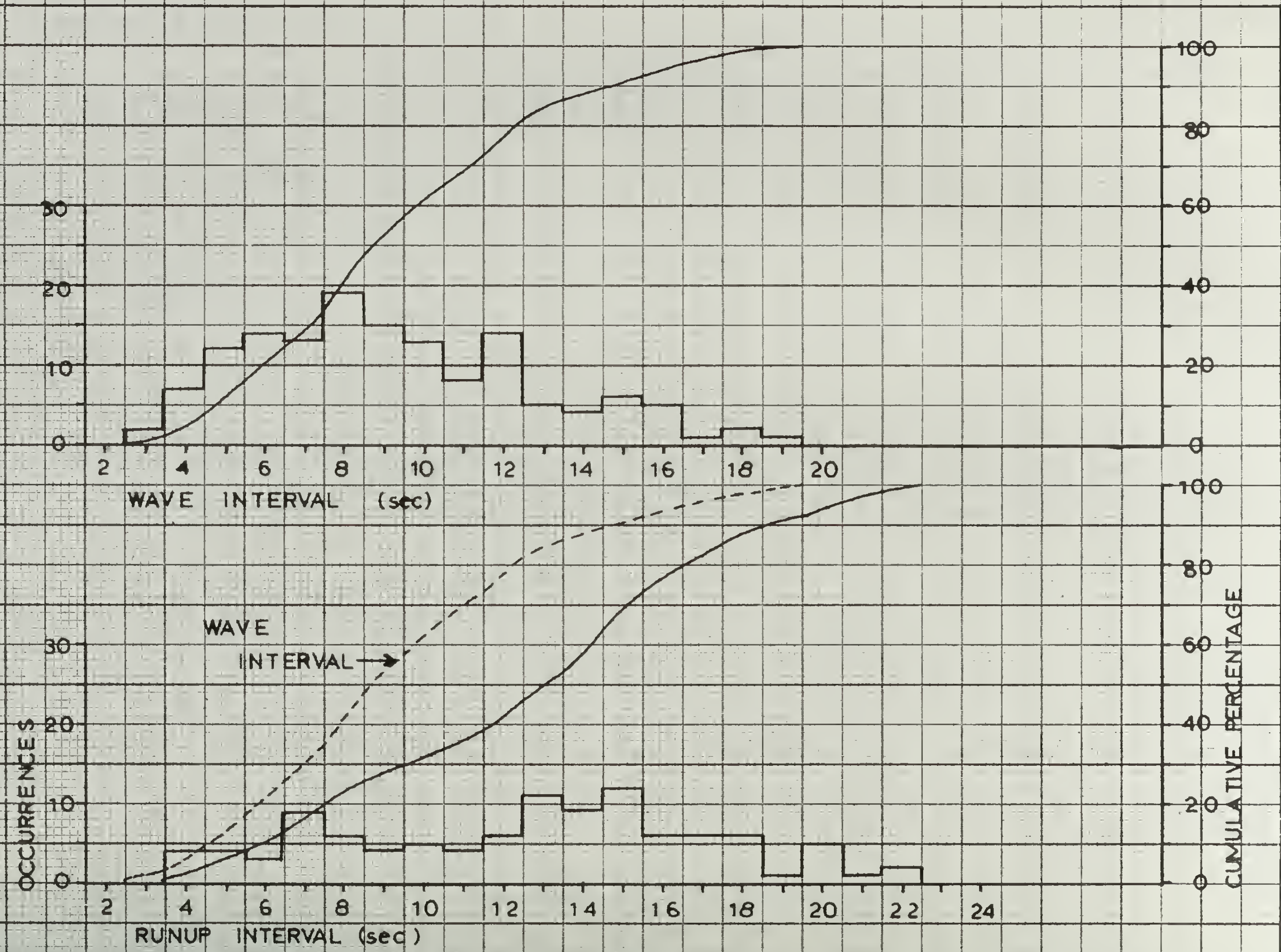


FIGURE 4e. INTERVAL DISTRIBUTIONS: RUN 5

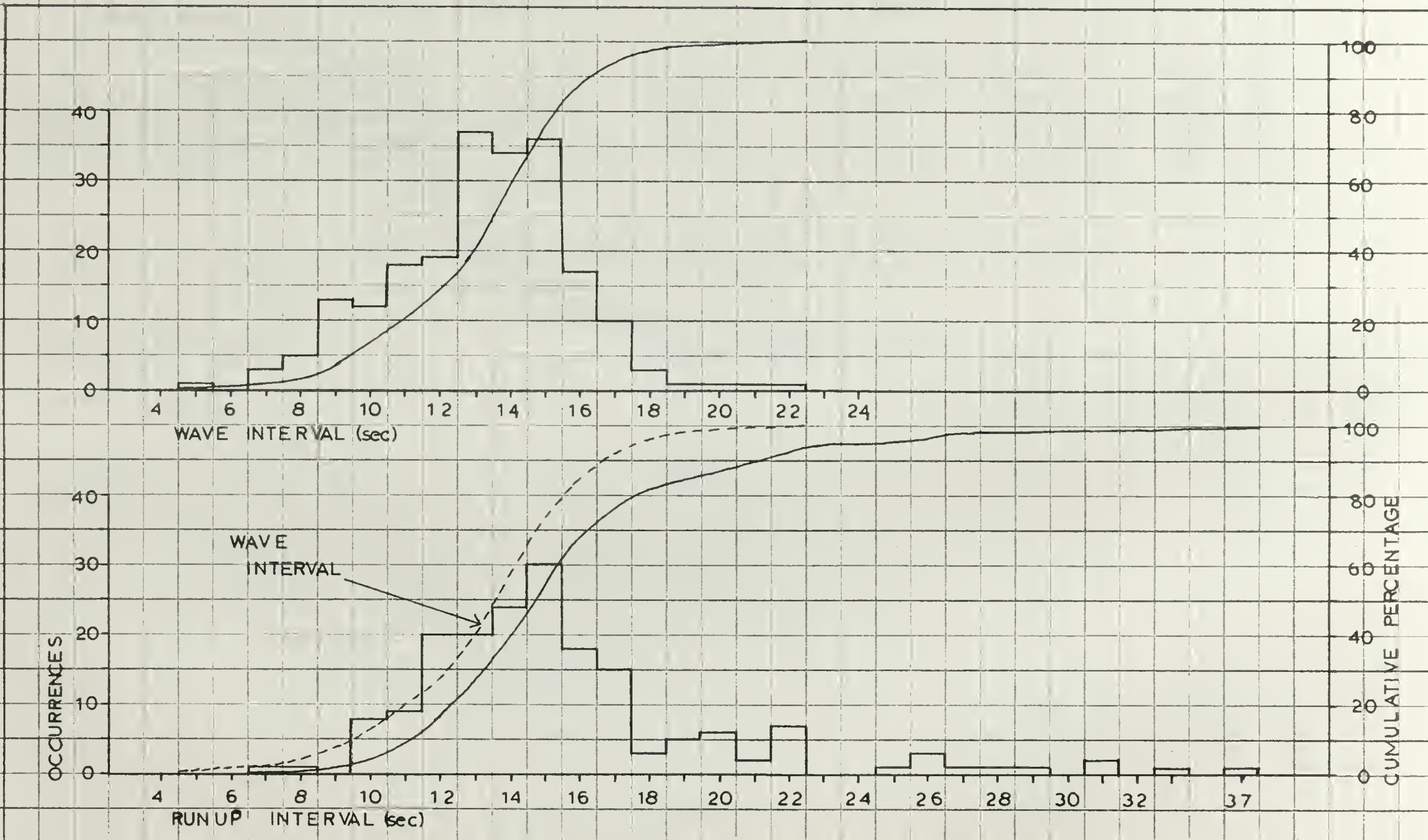


FIGURE 4f. INTERVAL DISTRIBUTIONS: RUN 6

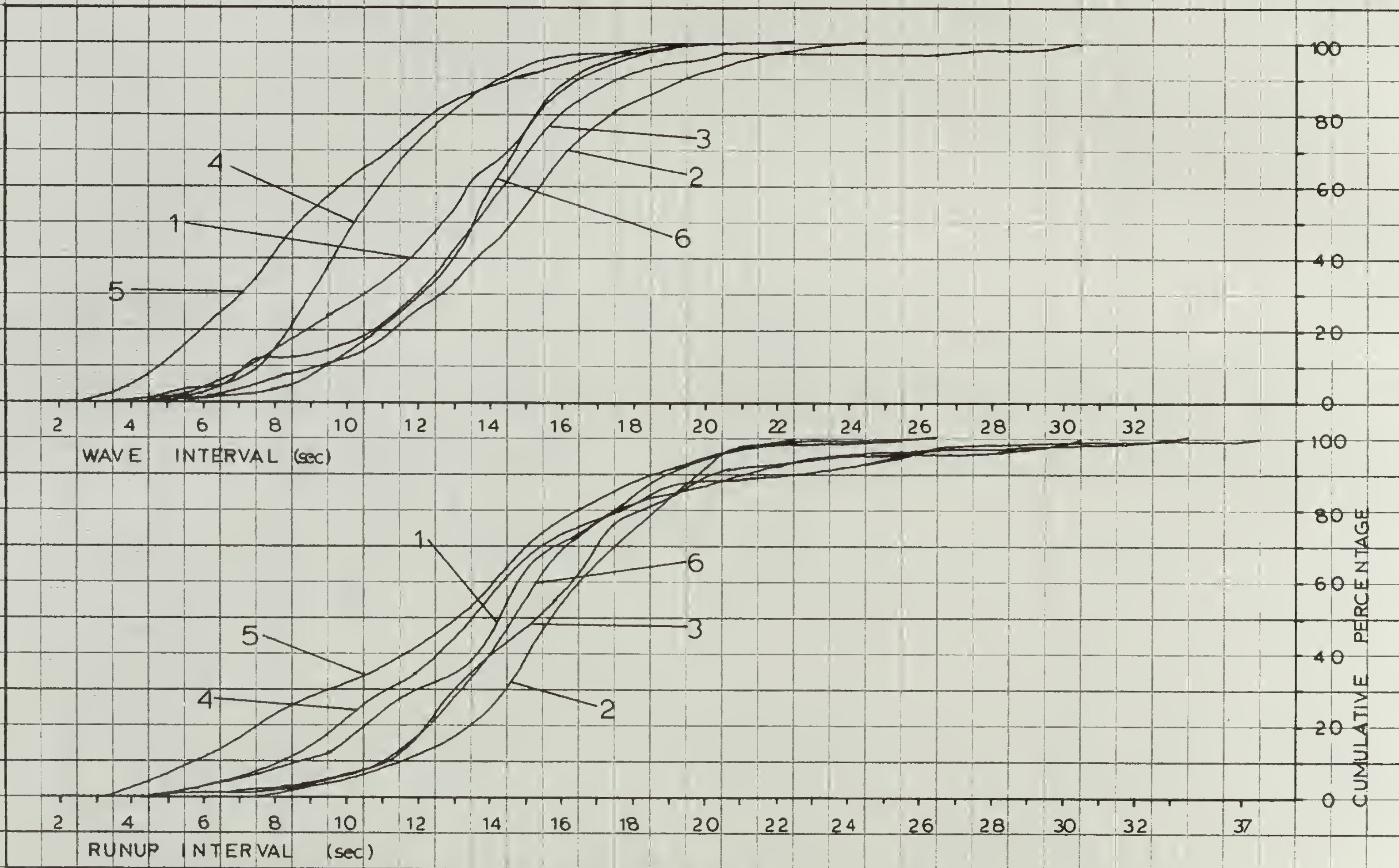


FIGURE 4g COMPOSITE OF CUMULATIVE INTERVAL DISTRIBUTIONS

TABLE III: SUMMARY OF INTERVAL DISTRIBUTIONS

| Run | Number of Runup Occurrences | Number of Waves | Ratio of Runup to Wave Occurrences | Median Wave Interval | Median Runup Interval | Difference Between Median Intervals | Range of Wave Intervals (90%-10%) | Range of Runup Intervals (90%-10%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 75 | 85 | .88 | 12.7 sec | 14.3 sec | 1.6 sec | 9.2 sec | 10.2 sec |
| 2 | 118 | 130 | .91 | 14.7 | 15.7 | 1.0 | 10.1 | 8.0 |
| 3 | 62 | 73 | .85 | 13.7 | 15.4 | 1.7 | 10.1 | 8.7 |
| 4 | 132 | 179 | .74 | 10.3 | 13.4 | 3.1 | 6.5 | 14.3 |
| 5 | 105 | 141 | .75 | 8.8 | 13.1 | 4.3 | 9.9 | 12.2 |
| 6 | 180 | 212 | .85 | 13.5 | 14.8 | 1.3 | 6.8 | 10.0 |

occurrence having a long interval, as will be discussed in a later section. It is interesting to note that Run 4 had the smallest range of wave intervals, but the largest range of runup intervals.

b. Wave-Crest Elevation and Runup Distributions

The frequency distributions of wave-crest elevations and runup values for each set of observations are shown in Figures 5a through 5g. Table IV summarizes the properties of these distributions. The significant wave-crest elevations shown in the table are the average of the highest third of the recorded values for each run, uncorrected for hydrodynamic damping. Similarly, the significant runup values are the average of the highest third of all the runup values recorded for the run.

The cumulative percentage curves of wave-crest elevation for the first five runs are very similar, and the curves approximately coincide on the composite plot in Figure 5g. The distribution of wave-crest elevations during Run 6 indicates a train of waves significantly larger than in the other runs. Most of the larger waves during this set of observations occurred as members of well-defined wave groups. The waves between the groups were generally smaller and less uniform.

The cumulative curves of runup for Runs 1 through 4 are very similar to one another and nearly coincide when plotted together in Figure 5g. The runup values for Run 6 had a much wider distribution range, as did the wave-crest elevations for that run. During Run 5 an unusual distribution of runup values was recorded. The range of values was narrow, and the median value was nearly identical to the median value of Run 6. The cumulative curve for the fifth run indicates that the runup values are larger than would be expected from the distribution of wave-crest elevations offshore.

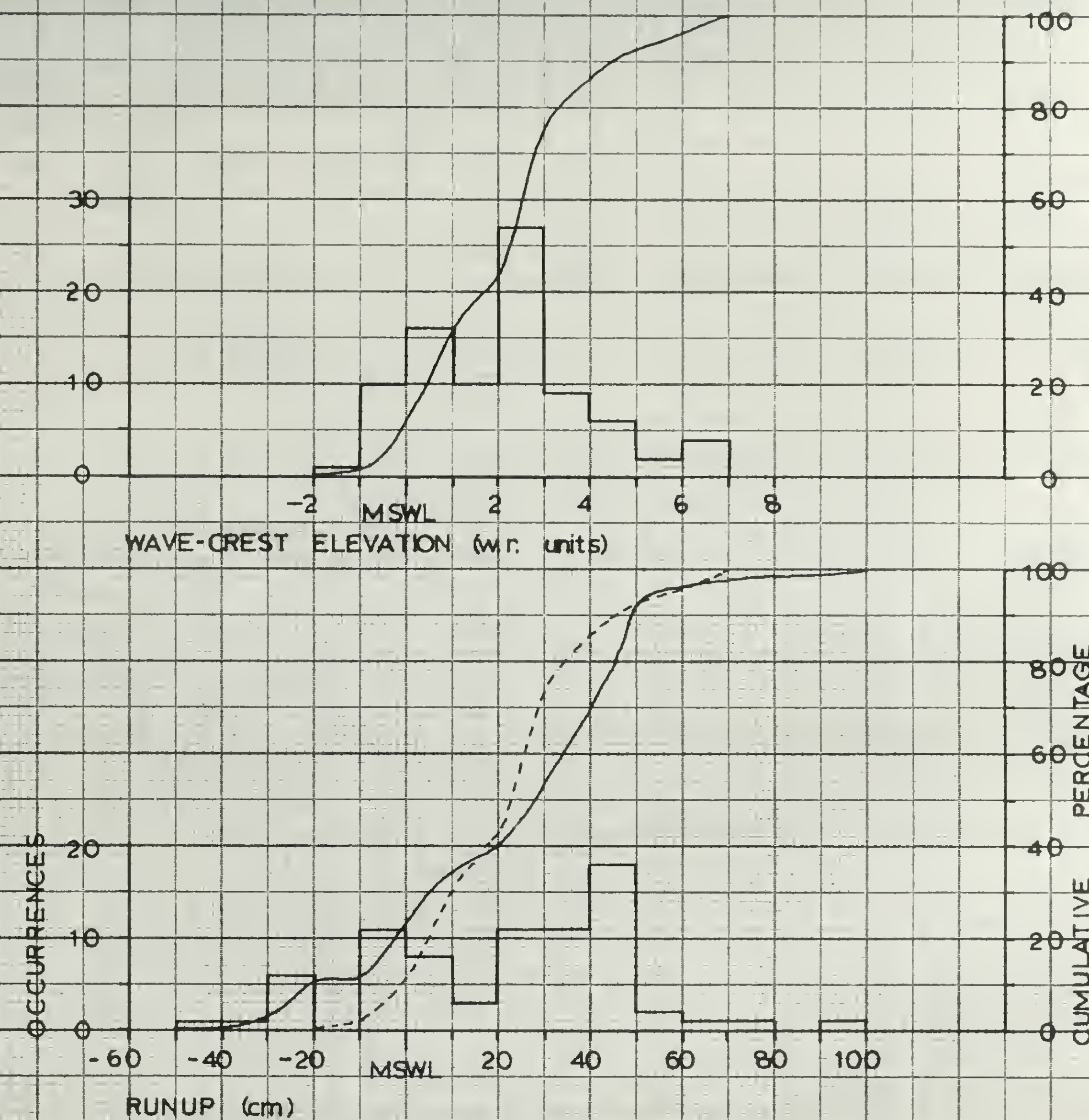


FIGURE 5a. WAVE-CREST ELEVATION AND RUNUP DISTRIBUTIONS: RUN 1

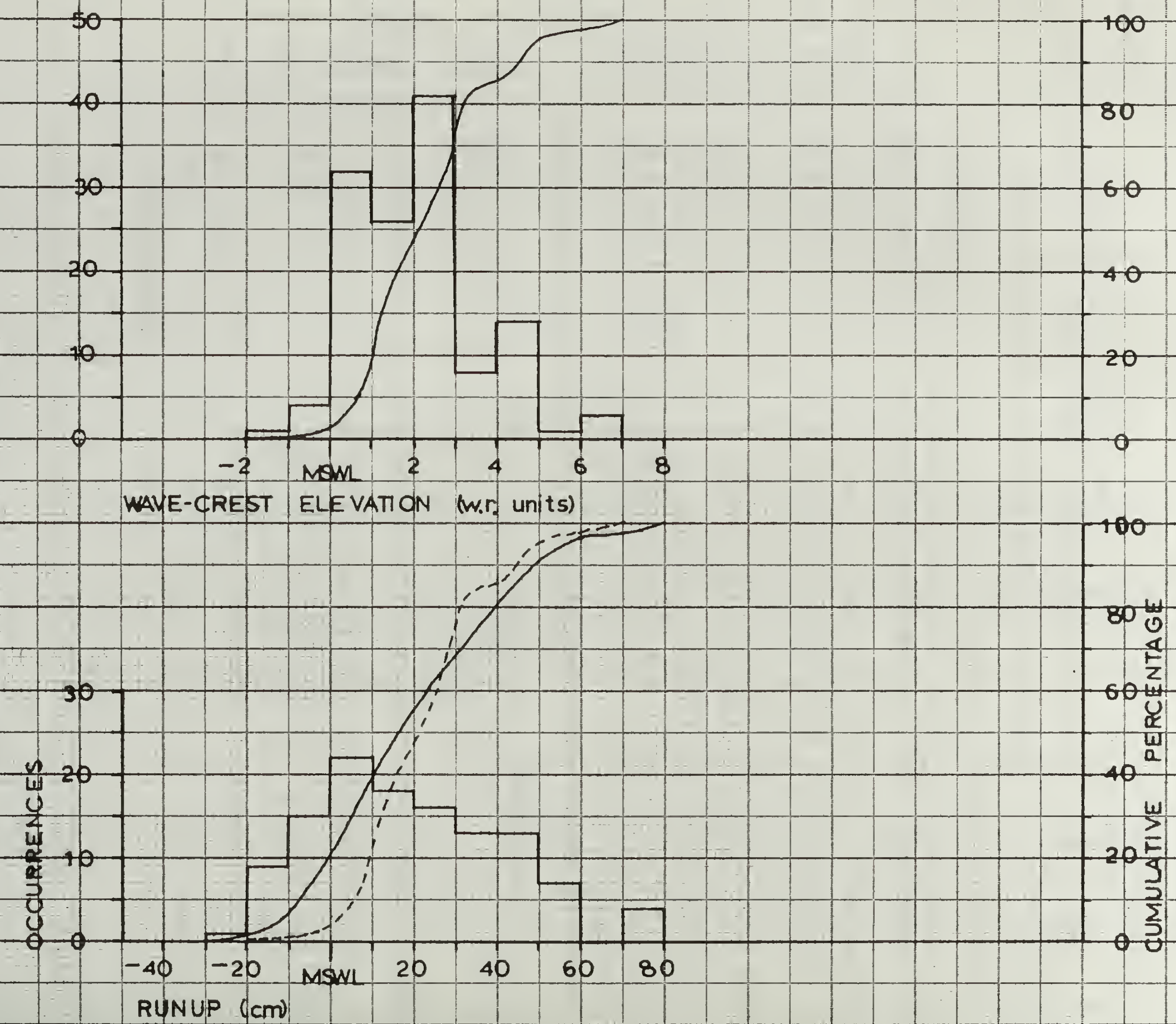


FIGURE 5b. WAVE-CREST ELEVATION AND RUNUP DISTRIBUTIONS: RUN 2

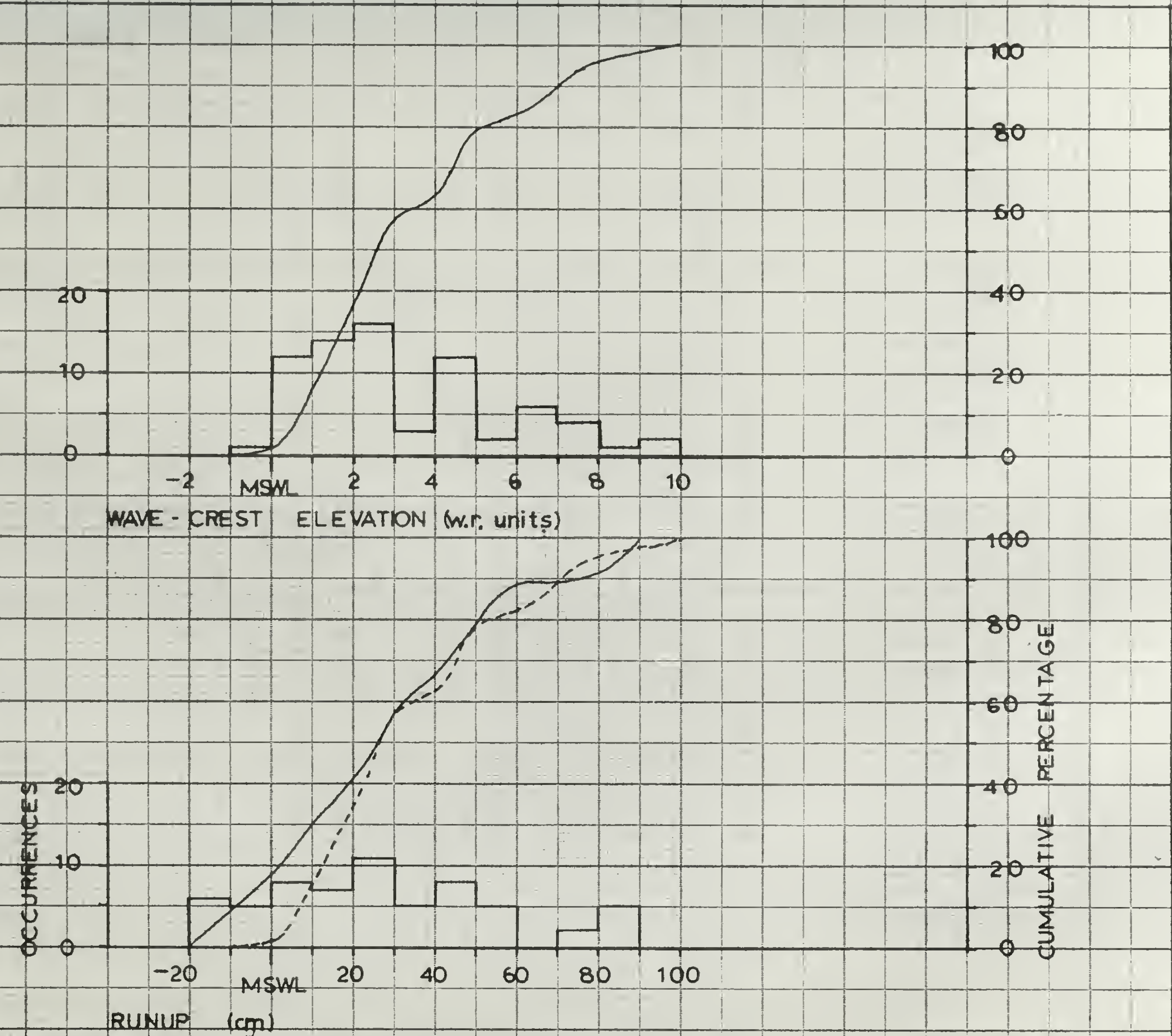


FIGURE 5c. WAVE-CREST ELEVATION AND RUNUP DISTRIBUTIONS: RUN 3

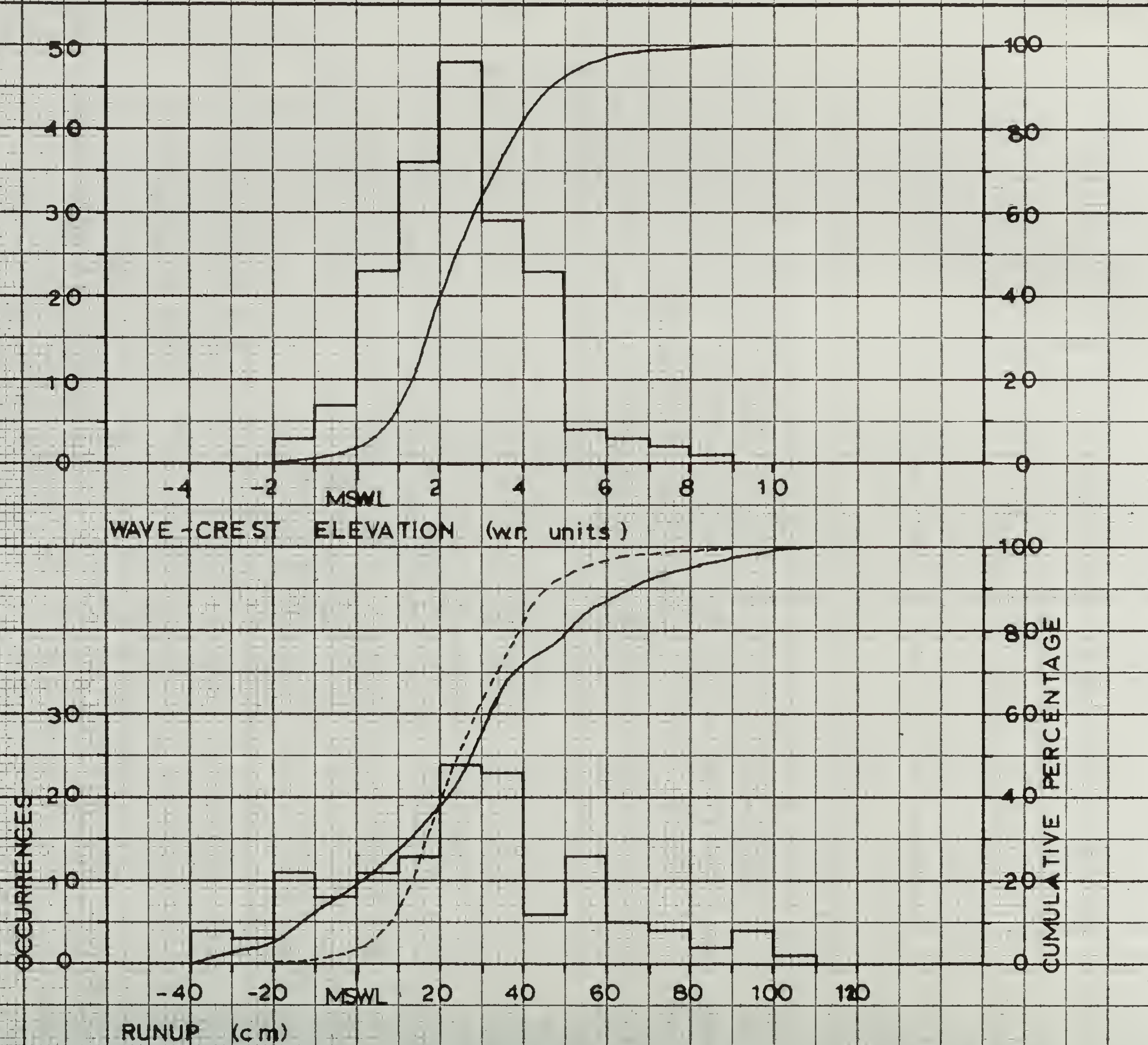


FIGURE 5d WAVE-CREST ELEVATION AND RUNUP DISTRIBUTIONS: RUN 4

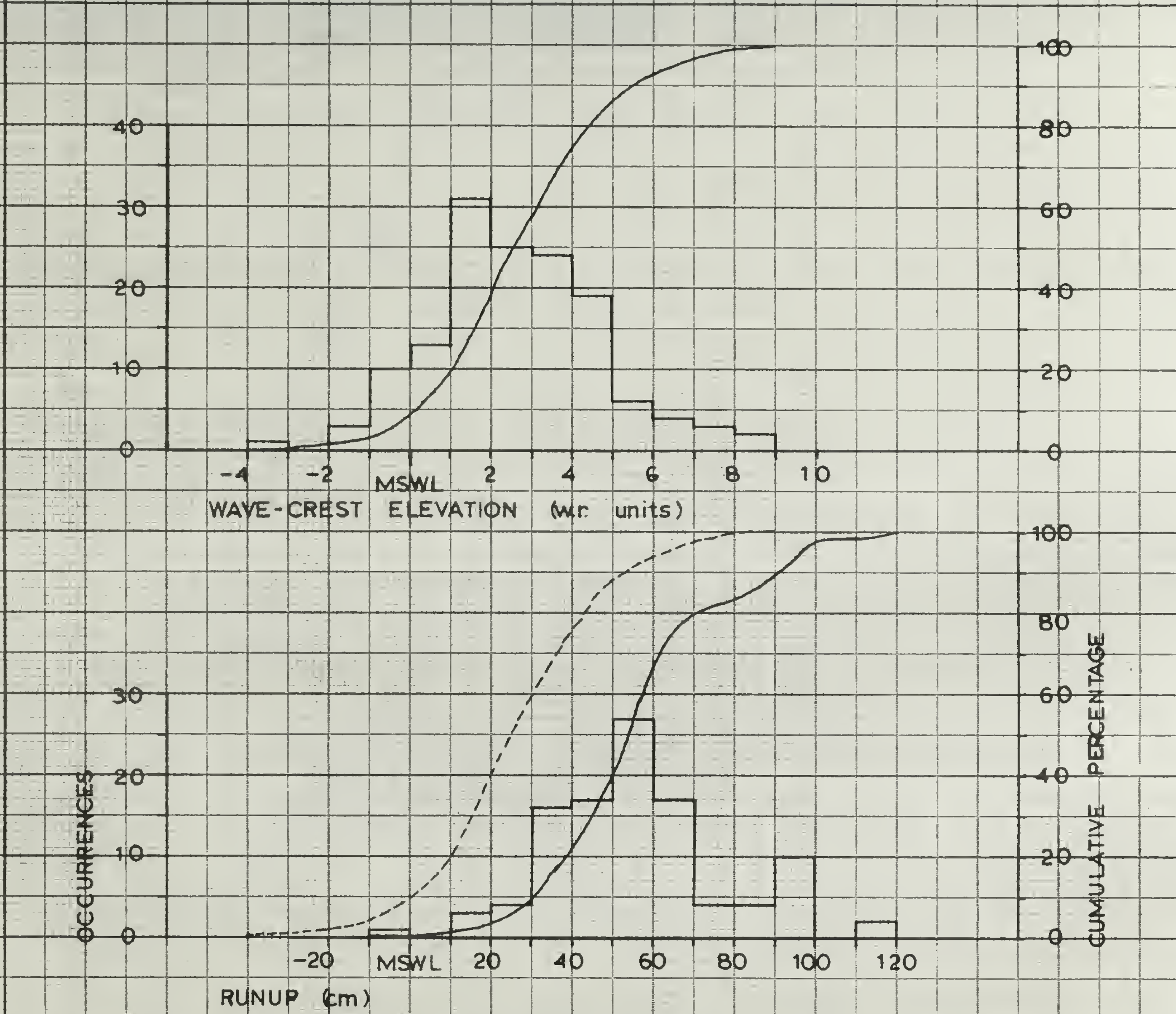


FIGURE 5e. WAVE-CREST ELEVATION AND RUNUP DISTRIBUTIONS: RUN 5

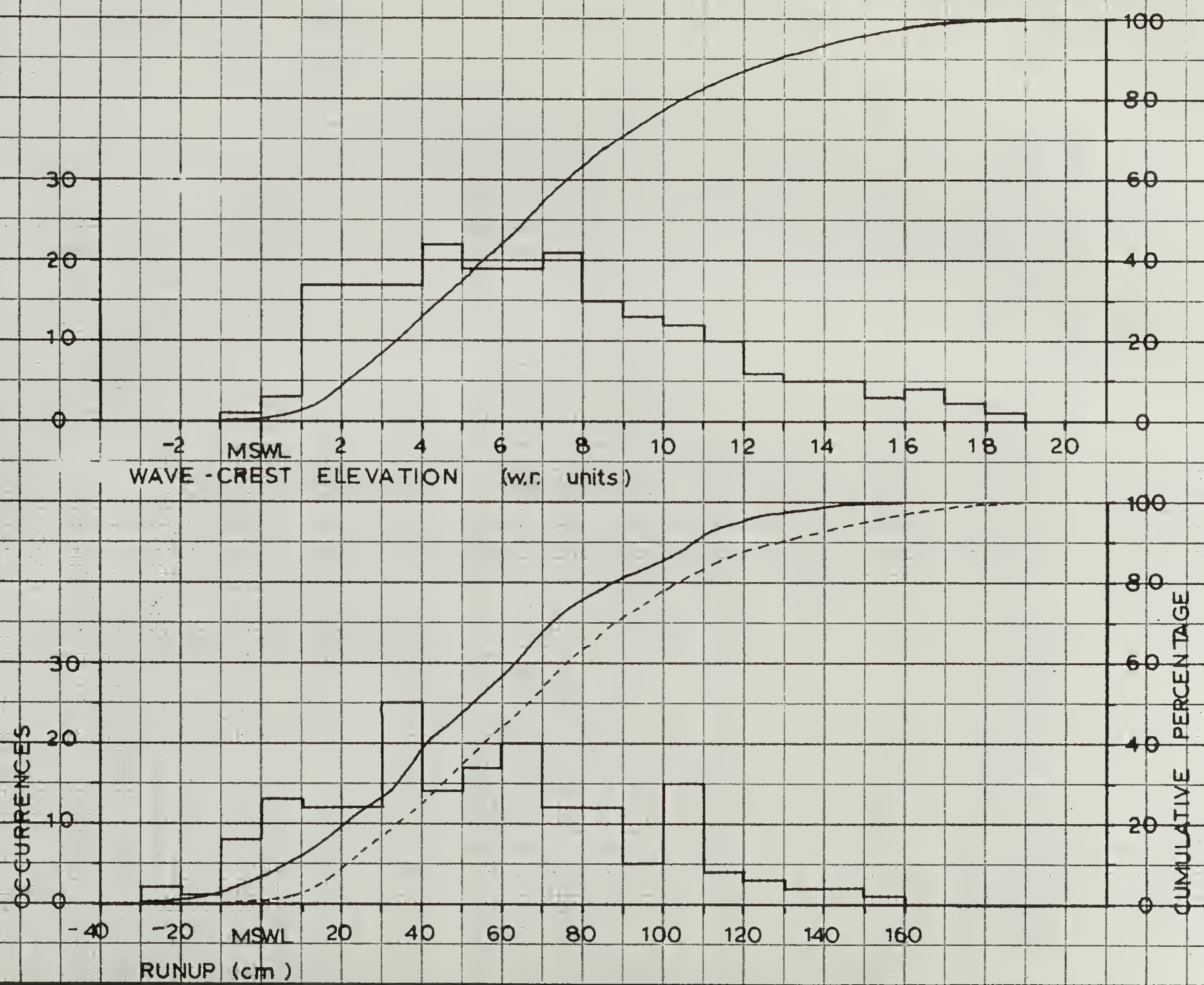


FIGURE 5f. WAVE - CREST ELEVATION AND RUNUP DISTRIBUTIONS: RUN 6

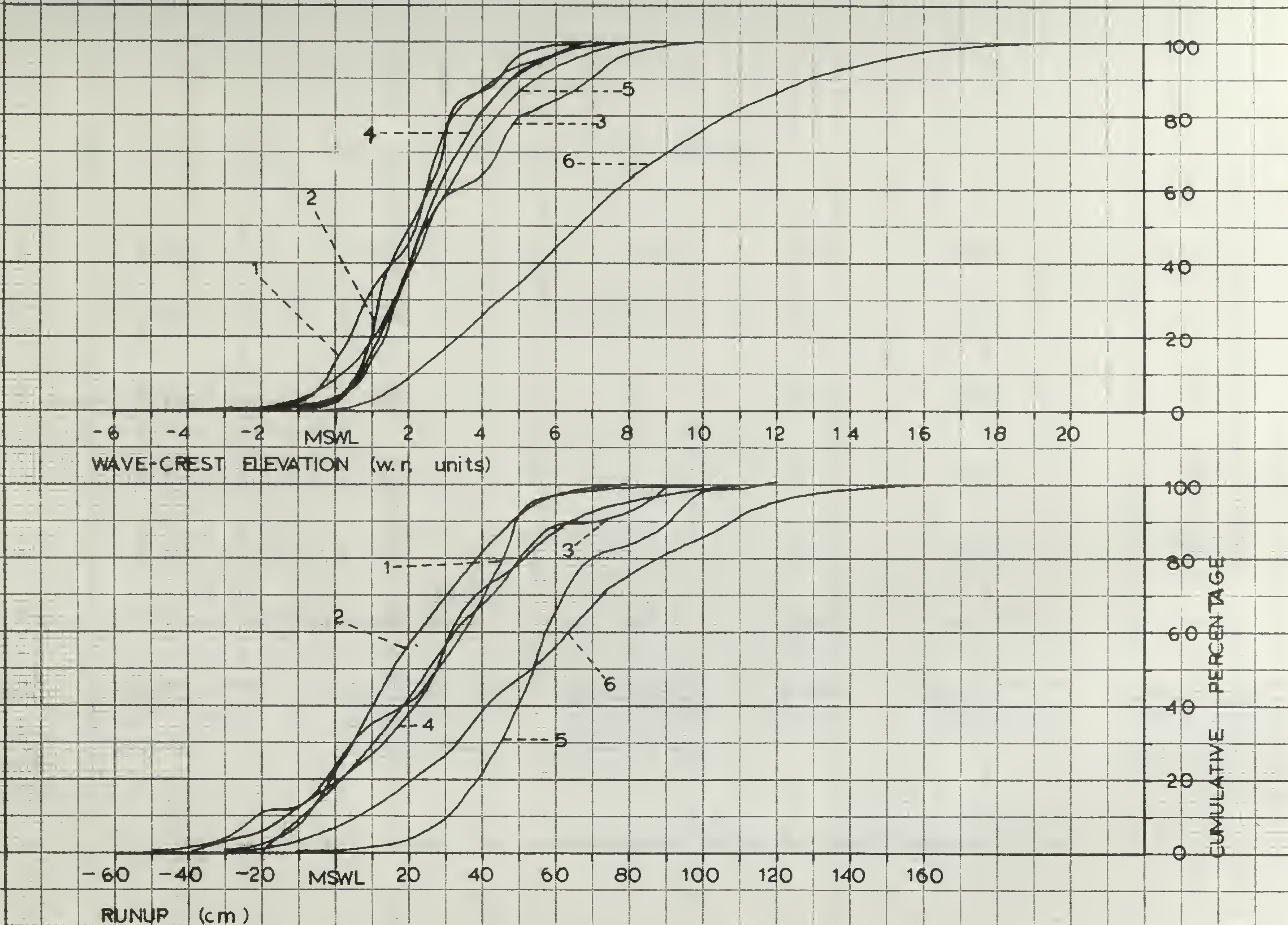


FIGURE 5a COMPOSITE OF CUMULATIVE WAVE-CREST ELEVATION AND RUNUP DISTRIBUTIONS

TABLE IV: SUMMARY OF WAVE-CREST ELEVATION AND RUNUP DISTRIBUTIONS

| Run | Median Wave-Crest Elevation (1) | Significant Wave-Crest Elevation (1) | Percent of Wave Crests Below MSWL | Median Runup | Significant Runup | Percent of Runup Values Below MSWL |
|---|---|---|---|---|---|---|
| 1 | 2.3 w.r. units | 4.0 w.r. units | 13% | 28 cm | 51.4 cm | 25% |
| 2 | 2.1 | 3.9 | 3 | 17 | 47.0 | 20 |
| 3 | 2.6 | 6.4 | 1 | 26 | 65.6 | 18 |
| 4 | 2.4 | 4.9 | 4 | 28 | 62.2 | 19 |
| 5 | 2.6 | 5.4 | 9 | 54 | 84.2 | 1 |
| 6 | 6.6 | 12.2 | 0.5 | 52 | 102.2 | 6 |

(1) At the sensor, uncorrected for hydrodynamic damping.

The reasons for the relatively larger runup values of the fifth run are not known. One possible contributing factor may have been the steeper beach face that prevailed during Run 5, as shown in Figure 2. The difference in beach slope was slight but may have altered the runup pattern.

It can be noted in the cumulative curves and in Table IV that up to 13 per cent of the wave crests in a given run lay below the MSWL. The distributions of runup values show an unexpectedly large number of negative values, amounting to as much as 25 per cent of the runup occurrences in a given set of observations. These negative values represent maximum points of uprush that were actually below MSWL. The percentage of negative runup values recorded during Runs 5 and 6 were very low. The reasons for this are not known, but it is possible that the combined factors of initially steeper waves and slightly greater beach slopes during these runs may have resulted in fewer negative runup values.

c. Travel-Time Distributions

The approximate time for a wave to travel from the location of the wave sensor, marked by a buoy, to its point of maximum runup on the beach, was determined visually by timing waves with a stop watch. Most times fell in a narrow range between 40 and 45 seconds, which is consistent with the travel times expected from shallow-water wave theory.

After a set of runup values and wave-crest elevations for a given run were tabulated, they were plotted against time on separate graphs. Vertical scales were selected to give plots of similar size. The two plots were then superimposed and offset along the time axis by about 43 seconds, the average travel time from the sensor to the beach. In all cases the two curves matched closely and an adjustment of no more than

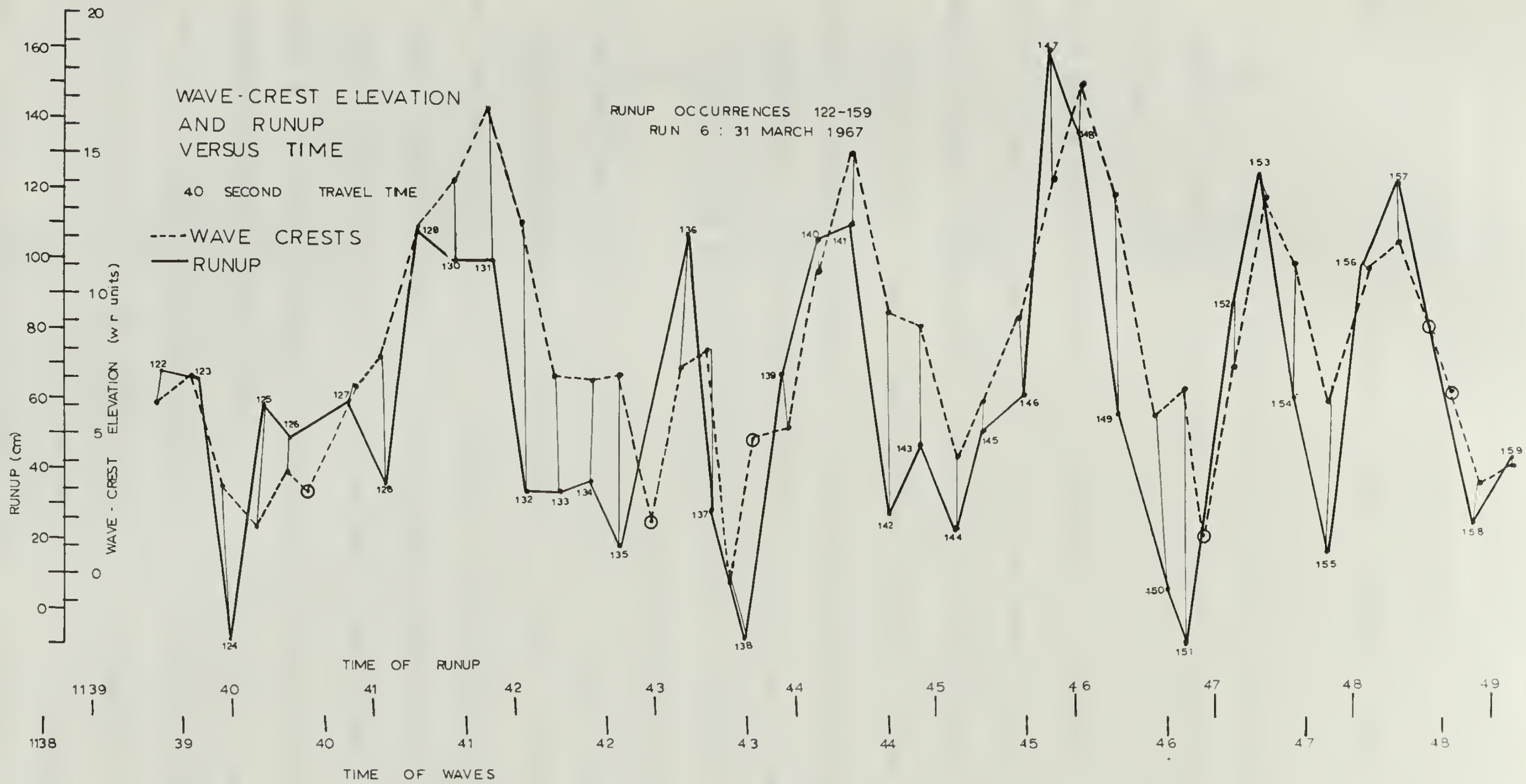


FIGURE 6. COMPOSITE TIME PLOT

three seconds was required to obtain the best fit of high and low points on both curves. Figure 6 is an excerpt from the composite time plot for Run 6. The similarity of the two curves is apparent, particularly in the close matching of their maximum and minimum points.

Using the composite time plots it was possible to relate each runup occurrence to a specific wave recorded offshore. Because the number of waves recorded during each observation period exceeded the number of runup occurrences during that period, not every wave was represented by a runup occurrence. In Figure 6, circled points represent waves with which a runup occurrence was not directly related. It is likely that each of these waves combined with the next wave in sequence to produce a single runup occurrence. Table V shows the number of runup occurrences related to one wave only, and the numbers related to two, three, and four waves. As stated previously, the number of runup values related to two or more waves was much higher on days of wind waves. A total of five runup values were recorded that could not be related to a specific wave.

Occasionally the composite time plot did not clearly show to which of two possible waves a certain runup value was related. In these cases the correct relationship could be found by computing the difference between the time each wave appeared on the wave record and the time at which the runup under consideration had occurred. One of the two possible relationships always yielded a reasonable time difference, whereas the other was too large or too small to be correct.

The frequency distributions of travel time for each set of field observations are shown in Figures 7a and 7b. Table VI summarizes the properties of these distributions. The median values for the first four runs are very similar. The median values for the last two runs are

TABLE V: SUMMARY OF NUMBER OF WAVES RELATED TO EACH RUNUP OCCURRENCE

| Run | Total Number of Runup Occurrences | Number Related to 1 Wave | Number Related to 2 Waves | Number Related to 3 Waves | Number Related to 4 Waves | Number Not Related to a Specific Wave |
|---|---|---|---|---|---|---|
| 1 | 75 | 63 | 11 | 0 | 0 | 1 |
| 2 | 118 | 106 | 12 | 0 | 0 | 0 |
| 3 | 62 | 50 | 10 | 1 | 0 | 1 |
| 4 | 132 | 90 | 35 | 5 | 1 | 1 |
| 5 | 105 | 69 | 30 | 4 | 0 | 2 |
| 6 | 180 | 152 | 24 | 4 | 0 | 0 |

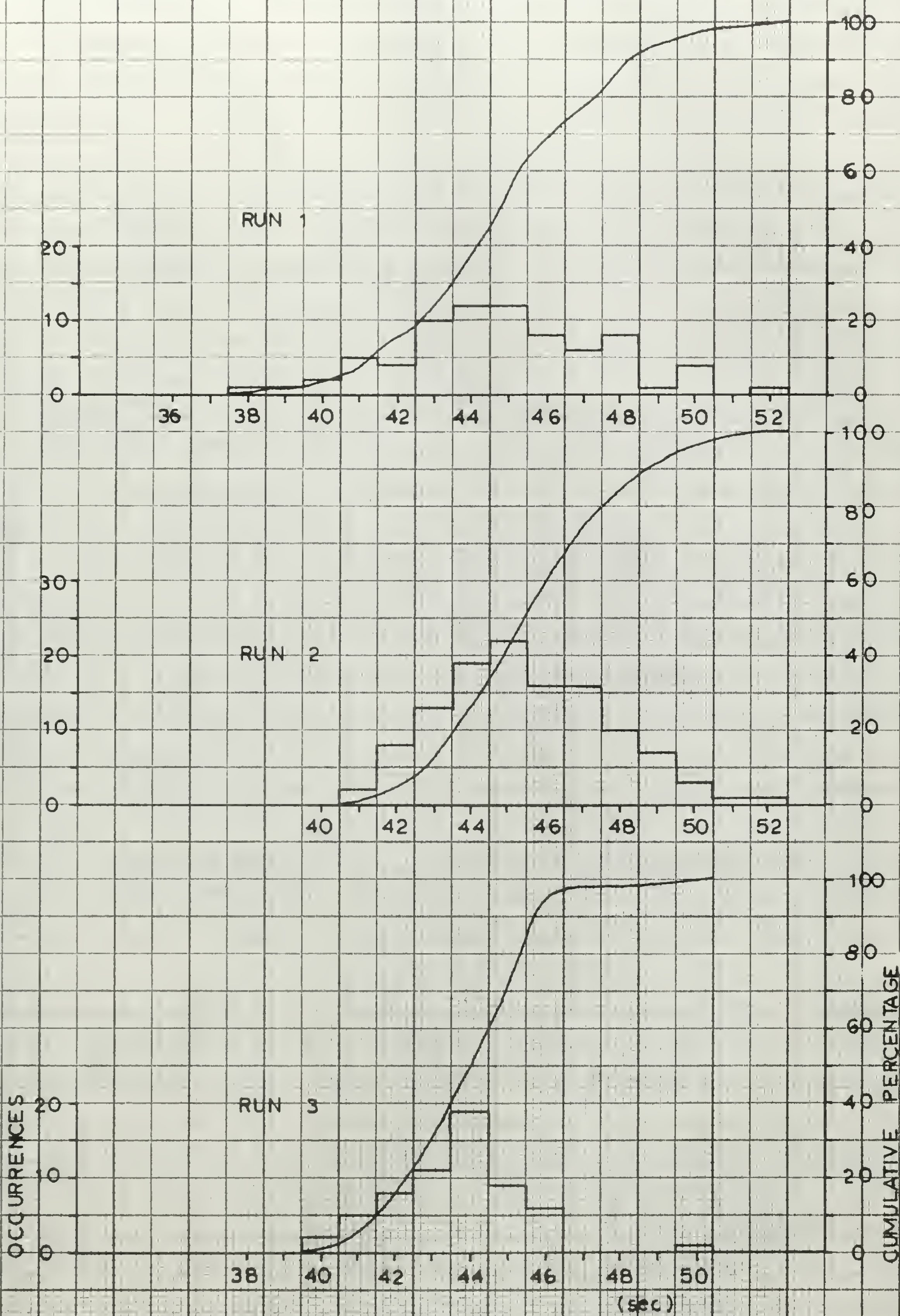


FIGURE 7a. TRAVEL TIME DISTRIBUTIONS

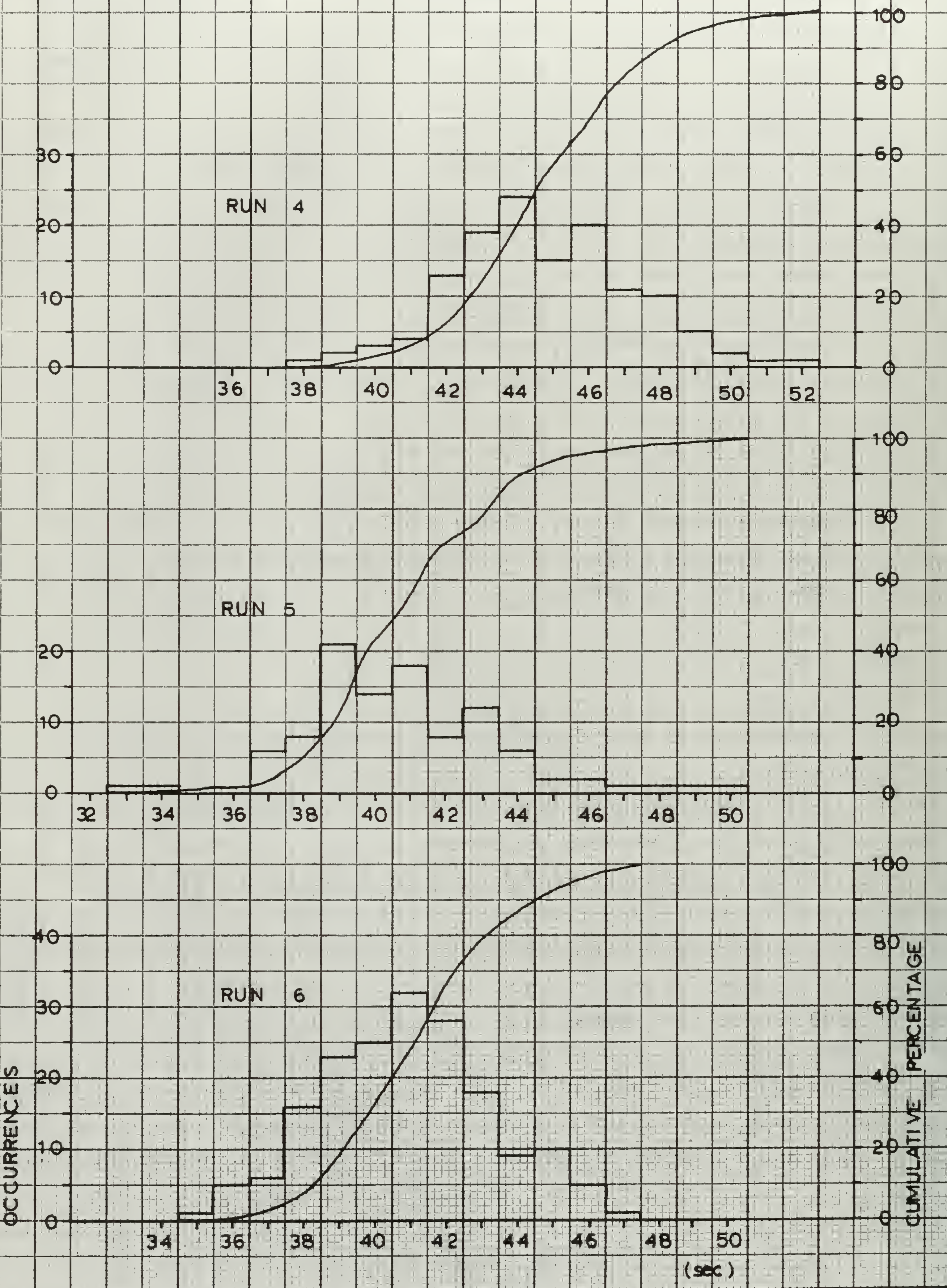


FIGURE 7b. TRAVEL TIME DISTRIBUTIONS

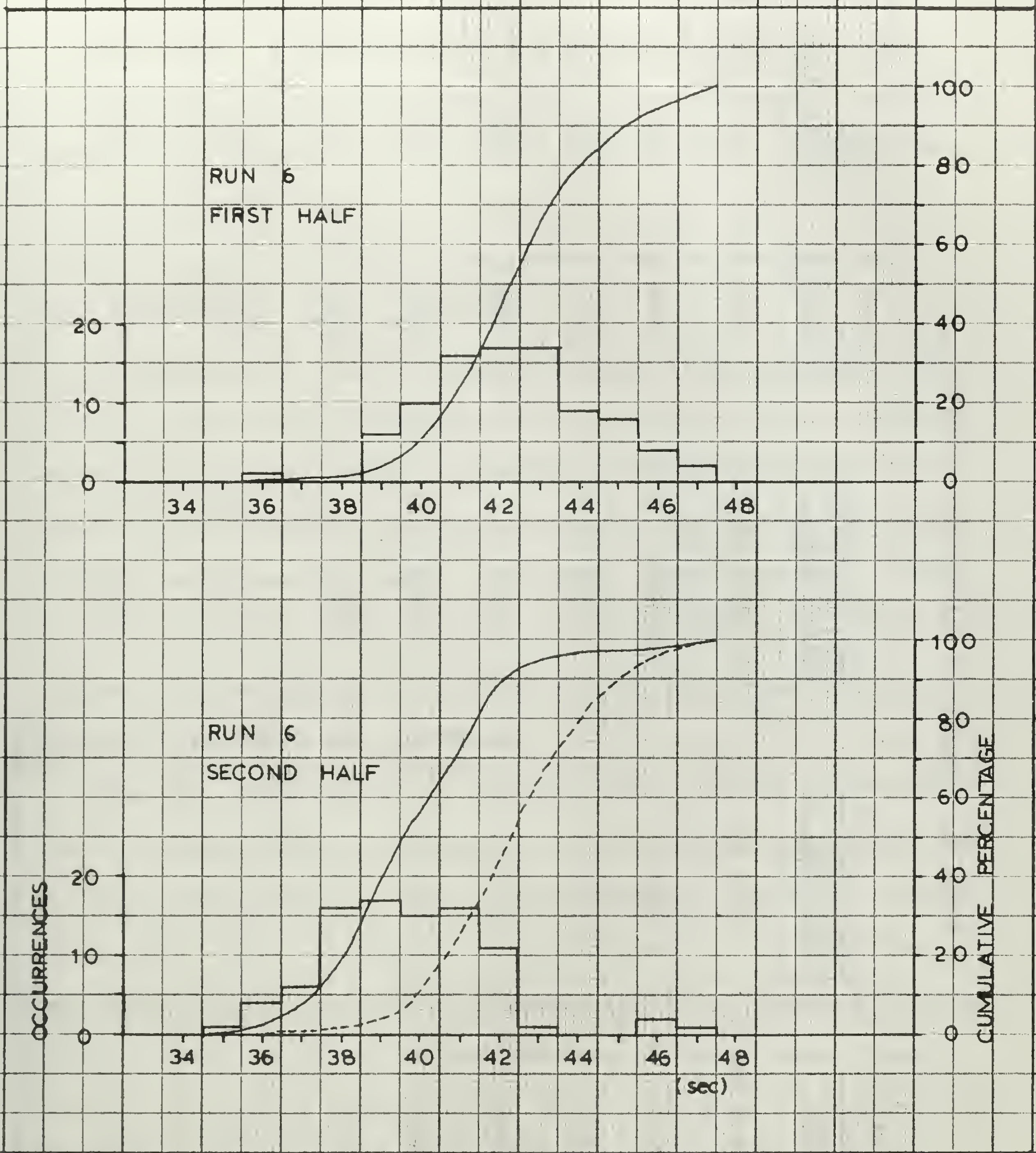


FIGURE 7c. TRAVEL TIME DISTRIBUTIONS

TABLE VI: SUMMARY OF TRAVEL-TIME DISTRIBUTIONS

| Run | Median Travel Time | 90th Percentile Travel Time | 10th Percentile Travel Time | Initial Wave Steepness | Mean Tide Level (1) |
|---|---|---|---|---|---|
| 1 | 44.8 sec | 48.4 sec | 41.4 sec | .0079 | 64 cm |
| 2 | 45.4 | 48.7 | 42.8 | .0038 | 62 |
| 3 | 43.9 | 45.6 | 41.4 | .0092 | 32 |
| 4 | 44.5 | 48.0 | 41.8 | .0138 | 97 |
| 5 | 40.6 | 44.1 | 38.0 | .0221 | 98 |
| 6 | 41.0 | 44.4 | 38.0 | .0202 | 27 |
| 6 (First Half) | 42.3 | 45.1 | 39.8 | .0202 | 24 |
| 6 (Second Half) | 39.5 | 42.0 | 37.3 | .0202 | 31 |

(1) Mean Still Water Level above MLLW.

nearly identical, but significantly shorter than the values for the first four runs. The 10th and 90th percentile values of the travel-time distributions for each run are also listed in the table, and in all cases do not vary more than 3.6 seconds from the median value for the corresponding run. This narrow range in the travel times from the recorder to the point of maximum runup assured correct matching of the waves offshore with runup occurrences.

Figure 7c shows the distribution of travel times for Run 6, with the first and second halves of the run considered separately. This run was conducted during a rapidly rising tide, and the differences in the travel-time distributions for the two halves of the run indicate that the waves moved shoreward faster as the water depth increased. Changes in travel time during other runs were not as apparent, as the other runs were made at times closer to low tide, and the tide change from the beginning to the end of each was small.

When the median travel time for each run is compared to the mean tide level during the run, the result is an irregular relationship (not shown), which suggests that factors other than water depth also contribute to travel time. In Figure 8 the median travel time for each run has been plotted against the initial steepness ($H_o'/T^2$) of the waves recorded during the run. The plot indicates that the initially steeper waves traveled shoreward at a faster speed, which is in agreement with earlier observations (U.S. Navy Hydrographic Office, 1958). In the cases of Runs 5 and 6, it is possible that the slightly altered beach profiles present may have been a contributing factor to the lower travel times for those runs. Thus the time for a wave to travel from the sensor to the point of maximum runup seems to depend upon the combined factors of

water depth, initial wave steepness, and beach profile.

The travel times for each individual wave-runup relationship for the six runs are tabulated in the Appendix.

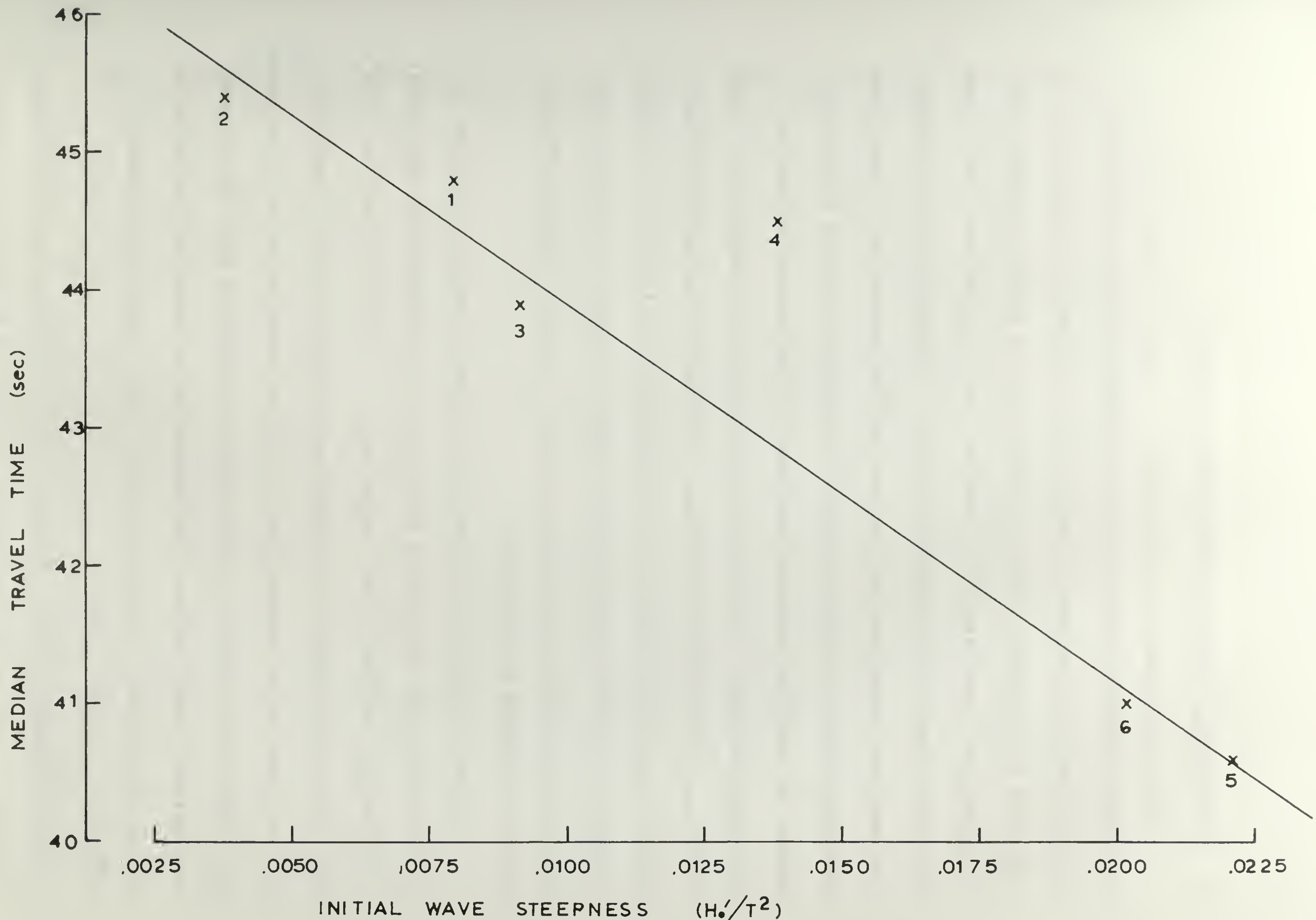


FIGURE 8. MEDIAN TRAVEL TIME VERSUS INITIAL WAVE STEEPNESS

## 4. Relationships Between Offshore Waves and Runup

After each runup value was related to a specific wave, plots of wave-crest elevation versus runup were prepared for each set of data. These individual plots are not shown, but in Figure 9 a composite of the six plots is presented. The runup values show a general increase with increased wave-crest elevation; however, for any given wave-crest elevation, the range of runup values is large. The individual plots showed the same wide variations, with no distinction between days of wind waves and days of swell. Runup occurrences identified in Figure 9 as being related to more than one wave have been plotted against the wave to which they are most closely related by travel time. Because one or more other waves contributed to the runup, the runup values generally were greater than those related to a single wave of similar size. There are a number of possible reasons for the large variations in the wave-runup relationships shown in the figure. Some of the most important reasons will be discussed in Section 5.

A general comparison of runup with offshore waves for each set of data has been made in terms of the ratio of the runup (R) to the initial (unrefracted) deep water wave height ($H_o'$). In Figure 10, the ratio $R/H_o'$ has been plotted against the initial wave steepness, $H_o'/T^2$ (from Table II), for each set of observations. With the exception of Run 5, in which the runup values seemed to be too large in comparison with the recorded wave heights (noted earlier), the points plotted show that the ratio decreases as the wave steepness increases. This trend is in agreement with the empirical results obtained in laboratory studies by Kaplan (1955) and Savage (1958). The magnitudes of the values are in agreement with Savage, but the runup-wave height ratios of Kaplan are an order of magnitude larger.

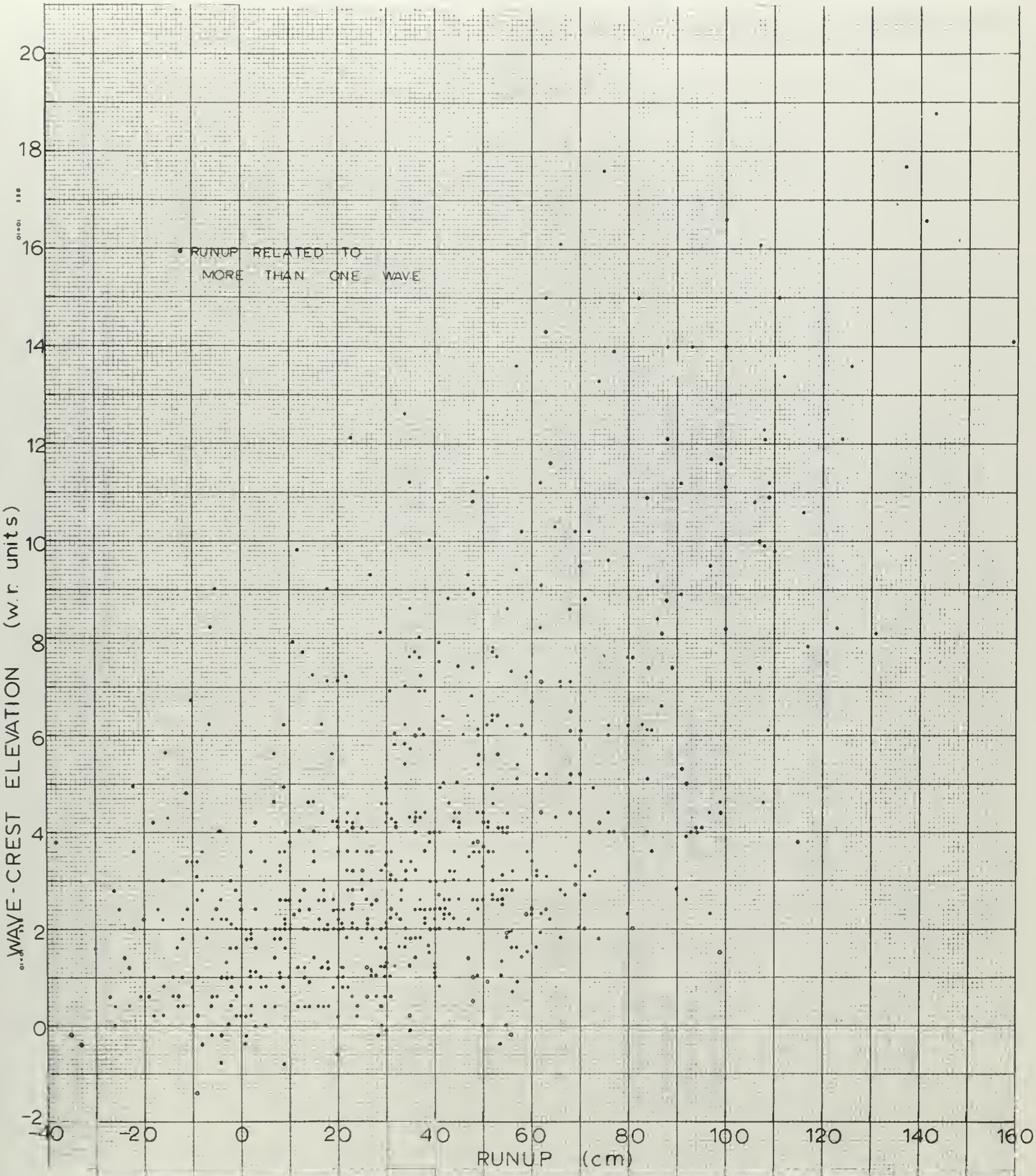


FIGURE 9. WAVE-CREST ELEVATION VERSUS RUNUR

TABLE VII: SUMMARY OF WAVE-RUNUP RELATIONSHIPS

| Run | Significant Wave-Crest Elevation At Sensor (1) | Significant Wave Height At Sensor (H) (2) | Significant Height of Unrefracted Deep-Water Waves ($H_o'$) (2) | Significant Runup (R) (3) | $R/H_o'$ |
|---|---|---|---|---|---|
| 1 | 4.0 w.r. units | 40.8 cm | 36.9 cm | 51.4 cm | 1.43 |
| 2 | 3.9 | 37.5 | 27.6 | 47.0 | 1.70 |
| 3 | 6.4 | 63.0 | 54.5 | 65.6 | 1.20 |
| 4 | 4.9 | 52.3 | 49.6 | 62.2 | 1.25 |
| 5 | 5.4 | 59.3 | 59.4 | 84.2 | 1.42 |
| 6 | 12.2 | 123.0 | 108.6 | 102.2 | 0.94 |

(1) Taken from Table IV. Values uncorrected for hydrodynamic damping.
(2) Converted from Table II (ft. to cm.). Values corrected for hydrodynamic damping.
(3) Taken from Table IV.

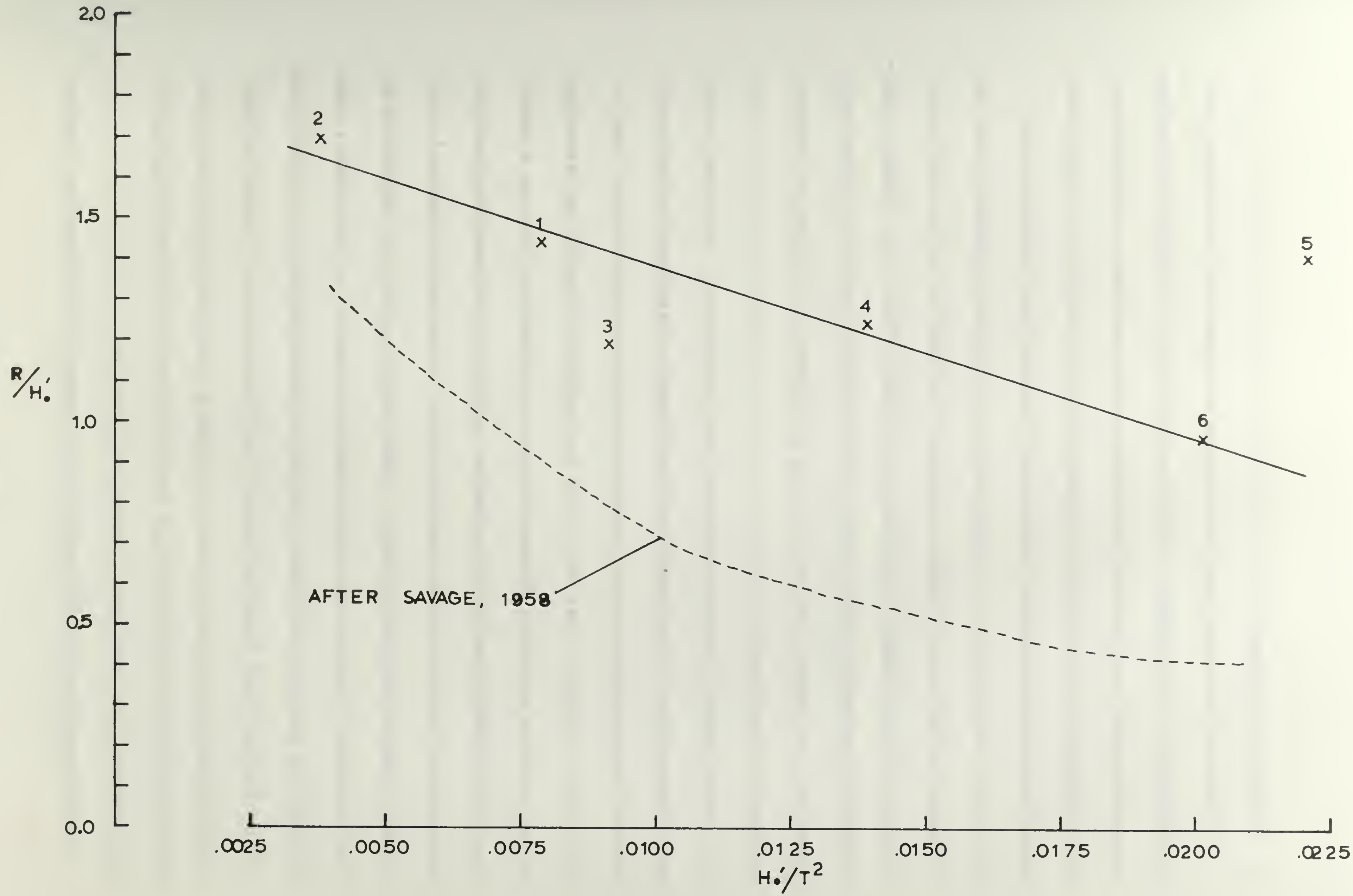


FIGURE 10. $R/H'_o$ VERSUS $H_o/T^2$

5. Foam-Line Interaction

Two considerations have been common to almost all theoretical and experimental runup studies. First, only solitary or periodic waves have been considered; and second, the effects of a wave upon the preceding and subsequent waves have been either neglected entirely, or only mentioned as an insignificant factor. In the preceding section it was shown that observations of runup resulting from the irregular waves of ordinary sea and swell showed a general relationship between the runup values and the offshore wave-crest elevations. There was, however, considerable variation in the runup values associated with any given crest elevation. A primary reason for this variation is interaction between successive foam lines.

Three types of interaction have been identified. The first, and most common type, is retardation of an incoming foam line by the backwash of the preceding runup. Retardation affects nearly every foam line, but to degrees that vary with the relative sizes of the waves involved and the intervals between them. As a foam line runs up a beach face, the velocity and amount of water moving up the beach decrease to the point of maximum runup, where the water momentarily stops and only a thin layer of water is present. Sand particles held in suspension at the forefront of the moving water commonly drop out at this point, leaving a swash mark on the beach. As the backwash begins, the velocity and volume flowing back down the beach steadily increase. A large backwash may possess so much energy that an incoming foam line, particularly one resulting from a small wave, may completely dissipate its energy against the backwash, so that little or no runup occurs.

When waves arrive in groups, it is common for the earlier, smaller

waves in the group to produce the largest runup, while later waves, though larger, produce small runup due to retardation by the large backwash of the initial waves. The results of retardation are apparent in Figure 6, where runup occurrences numbered 132, 137, 142, and 149 have small values in relation to the wave-crest elevations. The large amount of backwash from runup number 157 completely eliminated any runup from the next two small waves.

The second type of interaction is overtaking, which often occurs when a small foam line is followed closely by a large one. The small foam line is overtaken before it reaches its maximum shoreward extent, and the two foam lines combine to produce one runup value which is often greater than would normally be expected from the sizes of the individual waves involved. Overtaking commonly results when an incoming foam line is slowed by retardation, so that the next foam line overtakes it. In the time plot of Figure 6, foam lines have been overtaken by occurrences numbered 136, 139, and 152.

The third type of interaction is overriding. It is more subtle than retardation and overtaking, and cannot be identified in the time plots. Overriding commonly occurs when a wave is followed closely by a smaller wave. The larger wave breaks in deeper water and as it tumbles toward the beach as a foam line, its speed is diminished considerably and a general increase in water depth follows its passage. The smaller wave, unbroken, passes the point of breaking of the large wave and begins to catch up with its foam line. Because of the increase in water depth the second wave may move well up the beach before breaking. If it does not get caught in the backwash of the first foam line, it may produce a runup which is large for the size of the wave, and occurs only a

very short interval after the previous runup.

The different types of interaction can occur in several combinations, which depend on such factors as wave period, wave height, beach slope, and the relative size and spacing of successive waves. The interrelationships of all these factors are complicated and have not been investigated further in this study. Interaction of successive foam lines should be considered in all field observations of runup, however, because it is an important factor in explaining the large variations in observed runup values.

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## APPENDIX

## OFFSHORE WAVE AND RUNUP FIELD DATA

The data for each run are tabulated as follows:

Column 1: Runup Number (RN): Runup occurrences recorded during each observation period are numbered consecutively.

Column 2: Runup Value (RV): The vertical height above MSWL of each runup occurrence in centimeters.

Column 3: Wave-Crest Elevation (CE): The elevation of each wave-crest relative to MSWL is recorded in wave recorder units.

Column 4: Runup Interval (RI): The time in seconds between this runup and the previous runup.

Column 5: Wave Interval (WI): The interval in seconds between the appearance of this wave on the wave record and the time of the previous wave.

Column 6: Travel Time (TT): The difference in seconds between the appearance of this wave on the wave record and the time at which this runup value was recorded.

Notes following column 6:

(1) Wave not related to a specific runup occurrence, but probably combined with the following wave(s) to produce a single runup.

(2) Runup value related to more than one wave.

(3) Runup value not related to a specific wave.

| Runup Number RN | Runup Value RV | Wave-Crest Elevation CE | Runup Interval RI | Wave Interval WI | Travel Time TT | |
|---|---|---|---|---|---|---|
| | | RUN NUMBER ONE | 15 FEBRUARY 1967 | | | |
| 1 | 49 | 6.0 | 13 | 13 | 43 | |
| 2 | 20 | 2.0 | 19 | 15 | 47 | |
| 3 | -30 | 1.6 | 17 | 17 | 47 | |
| 4 | -26 | 0.0 | 11 | 12 | 46 | |
| 5 | -23 | 0.4 | 14 | 12 | 48 | |
| 6 | -32 | | 14 | | | (3) |
| 7 | 1 | -0.2 | 8 | 19 | 44 | |
| 8 | -6 | -0.2 | 5 | 7 | 42 | |
| 9 | 40 | 1.2 | 10 | 9 | 41 | |
| 10 | 44 | 3.6 | 13 | 9 | 45 | |
| 11 | 20 | 2.2 | 11 | 13 | 43 | |
| | | -1.6 | | 8 | | (1) |
| 12 | 3 | 1.0 | 15 | 7 | 43 | (2) |
| 13 | 5 | 0.0 | 15 | 11 | 47 | |
| | | 0.0 | | 8 | | (1) |
| 14 | 45 | 2.0 | 15 | 5 | 48 | (2) |
| 15 | 20 | 2.4 | 11 | 14 | 45 | |
| 16 | 8 | 2.0 | 15 | 13 | 47 | |
| 17 | -26 | 2.8 | 10 | 13 | 44 | |
| 18 | 46 | 6.0 | 10 | 10 | 44 | |
| 19 | 40 | 2.4 | 14 | 14 | 44 | |
| 20 | 43 | 3.2 | 14 | 13 | 45 | |
| 21 | 22 | 3.2 | 15 | 15 | 45 | |
| 22 | -48 | -0.4 | 17 | 16 | 46 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 23 | 40 | 2.4 | 11 | 12 | 45 | |
| 24 | 42 | 2.2 | 15 | 18 | 42 | |
| 25 | 64 | 2.2 | 14 | 13 | 43 | |
| | | 0.8 | | 7 | | (1) |
| 26 | 5 | 2.0 | 21 | 11 | 46 | (2) |
| 27 | -6 | 0.4 | 17 | 16 | 47 | |
| | | 0.2 | | 14 | | (1) |
| 28 | 8 | 1.8 | 22 | 12 | 43 | (2) |
| 29 | 70 | 5.0 | 14 | 12 | 45 | |
| 30 | 44 | 3.2 | 9 | 15 | 49 | |
| | | -1.0 | | 10 | | (1) |
| 31 | -1 | 0.2 | 18 | 11 | 46 | (2) |
| 32 | 13 | 0.4 | 14 | 19 | 41 | |
| 33 | 46 | 2.0 | 13 | 10 | 44 | |
| 34 | 1 | 2.0 | 17 | 13 | 48 | |
| 35 | 32 | 3.0 | 14 | 15 | 47 | |
| | | 2.0 | | 6 | | (1) |
| 36 | 40 | 2.4 | 11 | 7 | 45 | (2) |
| 37 | -26 | 0.4 | 11 | 8 | 48 | |
| 38 | 16 | 2.2 | 8 | 10 | 46 | |
| 39 | 30 | 2.0 | 12 | 13 | 45 | |
| 40 | 44 | 4.4 | 11 | 12 | 44 | |
| | | -0.4 | | 15 | | (1) |
| 41 | 35 | 0.2 | 26 | 5 | 50 | (2) |
| 42 | 36 | 2.4 | 8 | 15 | 43 | |
| 43 | 28 | 1.8 | 20 | 18 | 45 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 44 | 48 | 2.6 | 13 | 13 | 45 | |
| 45 | 52 | 6.4 | 15 | 16 | 44 | |
| 46 | 49 | 5.4 | 14 | 14 | 44 | |
| 47 | 52 | 6.4 | 15 | 15 | 44 | |
| 48 | -1 | 2.0 | 20 | 8 | 46 | |
| 49 | 43 | 4.6 | 12 | 15 | 43 | |
| 50 | 34 | 3.0 | 17 | 17 | 43 | |
| 51 | 45 | 4.4 | 16 | 18 | 41 | |
| 52 | 36 | 4.2 | 16 | 13 | 44 | |
| 53 | 13 | 1.2 | 16 | 16 | 44 | |
| 54 | -4 | -0.8 | 15 | 11 | 48 | |
| 55 | -27 | 0.6 | 10 | 6 | 52 | |
| 56 | -6 | 0.6 | 5 | 13 | 44 | |
| | | -0.6 | | 8 | | (1) |
| 57 | 39 | 2.0 | 16 | 9 | 43 | (2) |
| 58 | 30 | 1.2 | 14 | 15 | 42 | |
| 59 | 93 | 4.0 | 15 | 15 | 43 | |
| 60 | 41 | 2.0 | 16 | 12 | 46 | |
| 61 | -4 | 1.0 | 19 | 17 | 48 | |
| 62 | -4 | 2.6 | 15 | 13 | 50 | |
| 63 | -4 | 2.2 | 6 | 11 | 45 | |
| 64 | 22 | 3.6 | 11 | 15 | 41 | |
| 65 | 24 | 0.2 | 19 | 12 | 48 | |
| 66 | 20 | -0.6 | 14 | 12 | 50 | |
| | | 1.4 | | 15 | | (1) |
| 67 | -4 | -0.2 | 18 | 5 | 48 | (2) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 68 | -4 | 2.2 | 8 | 10 | 46 | |
| 69 | 34 | 2.0 | 7 | 8 | 45 | |
| | | 1.2 | | 10 | | (1) |
| 70 | 28 | 2.6 | 18 | 9 | 40 | (2) |
| | | -0.4 | | 12 | | (1) |
| 71 | 8 | 2.6 | 18 | 7 | 39 | (2) |
| 72 | 22 | 4.0 | 12 | 13 | 38 | |
| 73 | 39 | 3.8 | 18 | 14 | 42 | |
| 74 | 30 | 0.6 | 14 | 16 | 40 | |
| 75 | 22 | 0.8 | 17 | 16 | 41 | |

RUN NUMBER TWO 17 FEBRUARY 1967

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | -3 | 2.2 | | 44 | | |
| 2 | 26 | 2.0 | 18 | 15 | 47 | |
| | | 2.0 | | 14 | | (1) |
| 3 | 0 | 0.2 | 17 | 7 | 43 | (2) |
| 4 | -14 | 0.6 | 18 | 15 | 46 | |
| 5 | 50 | 2.6 | 16 | 16 | 46 | |
| 6 | 42 | 2.6 | 15 | 12 | 49 | |
| 7 | 38 | 2.2 | 15 | 18 | 46 | |
| 8 | 9 | 6.2 | 14 | 13 | 47 | |
| 9 | 12 | 2.6 | 18 | 18 | 47 | |
| 10 | 3 | 1.0 | 18 | 22 | 43 | |
| 11 | 40 | 2.2 | 14 | 11 | 49 | |
| 12 | 38 | 2.4 | 17 | 20 | 43 | |
| 13 | 42 | 2.6 | 19 | 16 | 46 | |
| 14 | -3 | 1.0 | 19 | 21 | 45 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 15 | 42 | 2.4 | 14 | 13 | 45 | |
| 16 | 50 | 6.2 | 17 | 15 | 47 | |
| 17 | -13 | 0.8 | 20 | 17 | 50 | |
| 18 | 12 | 0.4 | 10 | 14 | 46 | |
| 19 | 23 | 2.4 | 15 | 16 | 45 | |
| 20 | 30 | 1.0 | 16 | 16 | 45 | |
| 21 | 9 | 2.0 | 14 | 10 | 49 | |
| 22 | 3 | 2.4 | 15 | 18 | 46 | |
| 23 | -2 | 0.0 | 18 | 19 | 45 | |
| 24 | 5 | 0.4 | 17 | 17 | 45 | |
| 25 | 17 | 1.2 | 15 | 15 | 45 | |
| 26 | -13 | 1.6 | 14 | 11 | 48 | |
| | | 0.0 | | 11 | | (1) |
| 27 | 9 | 1.6 | 15 | 7 | 45 | (2) |
| 28 | 1 | 0.2 | 14 | 13 | 46 | |
| 29 | 16 | 0.4 | 17 | 19 | 44 | |
| 30 | -7 | 1.8 | 17 | 16 | 45 | |
| 31 | 17 | 1.2 | 12 | 9 | 48 | |
| | | 0.4 | | 13 | | (1) |
| 32 | 44 | 2.2 | 19 | 11 | 45 | (2) |
| 33 | -10 | 0.8 | 23 | 20 | 48 | |
| 34 | 21 | 1.0 | 16 | 19 | 45 | |
| 35 | 41 | 1.0 | 12 | 14 | 43 | |
| 36 | -9 | 3.4 | 19 | 12 | 50 | |
| 37 | -2 | 1.6 | 13 | 15 | 48 | |
| 38 | 21 | 0.8 | 16 | 18 | 46 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 39 | 36 | 1.8 | 16 | 16 | 46 | |
| 40 | 39 | 3.0 | 15 | 17 | 44 | |
| 41 | 42 | 3.0 | 16 | 15 | 45 | |
| 42 | -18 | 1.0 | 18 | 15 | 48 | |
| 43 | 39 | 1.6 | 12 | 12 | 48 | |
| 44 | 10 | 1.0 | 15 | 20 | 43 | |
| 45 | 9 | 2.0 | 14 | 12 | 45 | |
| 46 | 48 | 3.8 | 16 | 15 | 46 | |
| 47 | -16 | 0.8 | 19 | 16 | 49 | |
| 48 | -1 | 1.6 | 20 | 22 | 47 | |
| 49 | 1 | -0.4 | 14 | 10 | 51 | |
| | | 0.6 | | 7 | | (1) |
| 50 | 5 | 2.0 | 15 | 14 | 45 | (2) |
| 51 | -13 | 0.4 | 17 | 13 | 49 | |
| | | 0.0 | | 8 | | (1) |
| 52 | -0 | -1.4 | 13 | 8 | 46 | (2) |
| 53 | 29 | -0.2 | 9 | 11 | 44 | |
| 54 | 4 | 0.8 | 18 | 15 | 47 | |
| 55 | -5 | 0.6 | 13 | 11 | 49 | |
| | | 0.8 | | 5 | | (1) |
| 56 | 3 | 1.6 | 11 | 8 | 47 | (2) |
| 57 | 29 | 2.0 | 10 | 13 | 44 | |
| 58 | 31 | 1.0 | 15 | 13 | 43 | |
| 59 | -2 | 0.4 | 19 | 15 | 47 | |
| | | 2.2 | | 17 | | (1) |
| 60 | 27 | 2.0 | 23 | 9 | 44 | (2) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 61 | 9 | 0.8 | 16 | 16 | 44 | |
| 62 | 2 | 0.4 | 15 | 15 | 44 | |
| 63 | 29 | 0.0 | 15 | 15 | 44 | |
| | | -0.2 | | 11 | | (1) |
| 64 | 53 | 2.6 | 16 | 7 | 41 | (2) |
| 65 | 9 | 2.2 | 19 | 13 | 48 | |
| 66 | 17 | 2.8 | 11 | 13 | 46 | |
| 67 | 10 | 2.0 | 18 | 16 | 48 | |
| 68 | 2 | 1.0 | 12 | 17 | 43 | |
| 69 | -0 | 1.0 | 14 | 15 | 42 | |
| 70 | -8 | 3.6 | 15 | 10 | 47 | |
| 71 | 55 | 2.8 | 13 | 16 | 44 | |
| 72 | 26 | 2.6 | 16 | 13 | 47 | |
| 73 | -19 | 0.6 | 16 | 13 | 50 | |
| | | 0.0 | | 7 | | (1) |
| 74 | 2 | 0.2 | 11 | 11 | 43 | (2) |
| 75 | 40 | 4.0 | 16 | 12 | 47 | |
| 76 | 41 | 4.0 | 17 | 17 | 47 | |
| 77 | 22 | 4.4 | 13 | 13 | 47 | |
| 78 | 27 | 3.0 | 15 | 17 | 45 | |
| | | -1.0 | | 14 | | (1) |
| 79 | 36 | 4.0 | 25 | 11 | 45 | (2) |
| 80 | 55 | 4.4 | 17 | 19 | 43 | |
| 81 | 76 | 4.4 | 13 | 15 | 41 | |
| 82 | 22 | 2.8 | 19 | 13 | 47 | |
| 83 | 19 | 2.0 | 20 | 23 | 44 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 84 | 17 | 2.0 | 20 | 18 | 46 | |
| 85 | 57 | 5.4 | 11 | 15 | 42 | |
| 86 | -22 | 2.0 | 20 | 14 | 48 | |
| 87 | 14 | 0.4 | 16 | 21 | 43 | |
| 88 | 37 | 1.8 | 20 | 19 | 44 | |
| 89 | 0 | 0.8 | 18 | 16 | 46 | |
| 90 | -20 | 0.6 | 15 | 19 | 42 | |
| 91 | 24 | 0.4 | 15 | 15 | 42 | |
| 92 | 25 | 2.8 | 20 | 20 | 42 | |
| 93 | 22 | 1.8 | 20 | 10 | 52 | |
| 94 | 19 | 2.6 | 8 | 11 | 49 | |
| 95 | 76 | 4.0 | 8 | 13 | 44 | |
| 96 | 24 | 4.4 | 15 | 14 | 45 | |
| 97 | 19 | 2.4 | 17 | 18 | 44 | |
| 98 | 17 | 2.0 | 17 | 15 | 46 | |
| 99 | -3 | 1.0 | 20 | 24 | 42 | |
| 100 | -13 | 0.4 | 13 | 11 | 44 | |
| 101 | 2 | 0.8 | 10 | 7 | 47 | |
| 102 | 33 | 2.6 | 8 | 8 | 47 | |
| | | 2.0 | | 6 | | (1) |
| 103 | 72 | 4.0 | 18 | 15 | 44 | (2) |
| 104 | 15 | 3.6 | 17 | 16 | 45 | |
| 105 | 40 | 4.0 | 15 | 15 | 45 | |
| 106 | -1 | 2.8 | 16 | 16 | 45 | |
| 107 | 1 | 1.8 | 18 | 17 | 46 | |
| | | 1.8 | | 11 | | (1) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 108 | 13 | 2.0 | 18 | 11 | 42 | (2) |
| 109 | 4 | 1.0 | 13 | 11 | 44 | |
| 110 | 49 | 2.6 | 15 | 16 | 43 | |
| 111 | 17 | 2.0 | 15 | 13 | 45 | |
| 112 | 42 | 4.2 | 14 | 16 | 43 | |
| 113 | 70 | 4.4 | 15 | 14 | 44 | |
| 114 | 30 | 4.2 | 18 | 18 | 44 | |
| 115 | 33 | 2.8 | 16 | 17 | 43 | |
| 116 | 55 | 6.2 | 15 | 16 | 42 | |
| 117 | 17 | 3.0 | 18 | 15 | 45 | |
| 118 | 32 | 5.8 | 13 | 16 | 48 | |

RUN NUMBER THREE 19 FEBRUARY 1967

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 34 | 3.2 | | 11 | 46 | |
| 2 | 81 | | 17 | | | (1) |
| 3 | 76 | 9.6 | 12 | 30 | 46 | (2) |
| | | 2.2 | | 17 | | (1) |
| 4 | 3 | 4.2 | 30 | 16 | 42 | (2) |
| 5 | 76 | 6.0 | 15 | 15 | 42 | |
| 6 | 38 | 6.0 | 17 | 15 | 44 | |
| 7 | 14 | 4.6 | 16 | 27 | 43 | (1) |
| | | 1.0 | | 15 | | (2) |
| 8 | -13 | 0.6 | 19 | 6 | 41 | |
| 9 | 21 | 2.4 | 17 | 15 | 43 | |
| 10 | 52 | 4.6 | 15 | 14 | 44 | |
| 11 | 47 | 6.4 | 16 | 15 | 45 | |
| 12 | 2 | 2.0 | 17 | 17 | 45 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 13 | 49 | 4.4 | 13 | 16 | 42 | |
| 14 | 36 | 4.2 | 19 | 15 | 46 | |
| 15 | -9 | 2.6 | 12 | 14 | 44 | |
| 16 | -9 | 2.0 | 13 | 16 | 41 | |
| 17 | -16 | 0.2 | 18 | 15 | 44 | |
| 18 | 20 | 0.2 | 12 | 13 | 43 | |
| 19 | 26 | 2.0 | 15 | 14 | 44 | |
| | | 0.6 | | 9 | | (1) |
| 20 | 47 | 1.4 | 19 | 10 | 44 | (2) |
| 21 | 36 | 4.4 | 14 | 14 | 42 | |
| | | 1.0 | | 11 | | (1) |
| 22 | 7 | 2.0 | 22 | 11 | 44 | (2) |
| 23 | 80 | 7.6 | 13 | 14 | 43 | |
| 24 | 37 | 7.6 | 15 | 12 | 46 | |
| 25 | 56 | 9.4 | 12 | 15 | 43 | |
| | | 6.4 | | 12 | | (1) |
| 26 | -20 | 2.2 | 28 | 15 | 44 | (2) |
| | | 0.6 | | 11 | | (1) |
| 27 | -9 | 0.2 | 17 | 7 | 43 | (2) |
| 28 | 52 | 2.6 | 10 | 12 | 41 | |
| | | -0.2 | | 7 | | (1) |
| 29 | 26 | 1.2 | 23 | 12 | 45 | (2) |
| 30 | -6 | 2.2 | 13 | 13 | 45 | |
| 31 | 42 | 2.2 | 20 | 20 | 45 | |
| 32 | 48 | 7.4 | 12 | 12 | 45 | |
| | | 1.2 | | 17 | | (1) |
| | | 1.2 | | 6 | | (1) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 33 | 24 | 2.0 | 30 | 12 | 40 | (2) |
| 34 | 2 | 1.0 | 17 | 13 | 44 | |
| 35 | 18 | 1.2 | 8 | 7 | 45 | |
| 36 | 22 | 4.0 | 10 | 11 | 44 | |
| 37 | -12 | 1.8 | 17 | 18 | 43 | |
| | | 0.0 | | 9 | | (1) |
| 38 | 20 | 1.6 | 17 | 7 | 44 | (2) |
| 39 | 9 | 4.0 | 13 | 14 | 43 | |
| | | 0.6 | | 6 | | (1) |
| 40 | 52 | 3.6 | 19 | 13 | 45 | (2) |
| 41 | 50 | 4.4 | 14 | 14 | 43 | |
| 42 | 12 | 2.4 | 15 | 15 | 43 | |
| 43 | 3 | 2.4 | 18 | 17 | 44 | |
| 44 | 81 | 7.6 | 11 | 15 | 40 | |
| 45 | 19 | 4.2 | 17 | 13 | 44 | |
| 46 | 49 | 5.6 | 20 | 20 | 44 | |
| 47 | 42 | 6.4 | 16 | 15 | 45 | |
| 48 | 22 | 4.2 | 17 | 18 | 44 | |
| 49 | 86 | 8.4 | 13 | 14 | 43 | |
| 50 | -16 | 3.0 | 20 | 13 | 50 | |
| 51 | 23 | 2.0 | 14 | 18 | 46 | |
| 52 | -12 | 1.0 | 11 | 11 | 46 | |
| | | 0.2 | | 4 | | (1) |
| 53 | -10 | 0.0 | 14 | 14 | 42 | (2) |
| 54 | 21 | 1.2 | 12 | 12 | 42 | |
| 55 | 7 | 1.4 | 13 | 11 | 44 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 56 | 19 | 0.8 | 12 | 12 | 44 | |
| 57 | 41 | 0.8 | 5 | 7 | 42 | |
| 58 | 21 | 2.0 | 13 | 16 | 41 | |
| 59 | 2 | 1.8 | 15 | 14 | 42 | |
| 60 | 83 | 6.2 | 14 | 15 | 41 | |
| 61 | 19 | 5.6 | 16 | 13 | 44 | |
| 62 | 17 | 4.4 | 16 | 16 | 44 | |

RUN NUMBER FOUR 3 MARCH 1967

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 1 | 38 | 4.4 | | 14 | 47 | |
| | | 2.8 | | 9 | | (1) |
| 2 | 32 | 0.8 | 23 | 13 | 46 | (2) |
| 3 | 43 | 2.0 | 10 | 11 | 45 | |
| | | 1.2 | | 9 | | (1) |
| 4 | -33 | -0.4 | 18 | 15 | 39 | (2) |
| 5 | 31 | 2.2 | 12 | 8 | 43 | |
| 6 | 35 | 3.4 | 14 | 11 | 46 | |
| | | 2.8 | | 9 | | (1) |
| 7 | 23 | 3.2 | 15 | 5 | 47 | (2) |
| 8 | 33 | 3.4 | 6 | 9 | 44 | |
| 9 | 32 | 4.2 | 14 | 13 | 45 | |
| | | 1.4 | | 10 | | (1) |
| 10 | 33 | 2.2 | 24 | 13 | 46 | (2) |
| 11 | 10 | 2.6 | 8 | 10 | 44 | |
| 12 | -12 | 2.2 | 13 | 10 | 47 | |
| 13 | 3 | 0.0 | 15 | 19 | 43 | |
| 14 | 85 | 3.6 | 9 | 9 | 43 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 15 | -4 | 2.2 | 16 | 11 | 48 | |
| 16 | -1 | 0.6 | 10 | 11 | 47 | |
| | | -1.2 | | 6 | | (1) |
| 17 | -2 | 0.8 | 10 | 8 | 43 | (2) |
| 18 | 47 | 3.0 | 9 | 7 | 45 | |
| 19 | 26 | 2.2 | 15 | 15 | 45 | |
| 20 | 70 | 2.0 | 7 | 10 | 42 | |
| 21 | 26 | 3.6 | 14 | 14 | 42 | |
| 22 | 0 | 2.6 | 15 | 8 | 49 | |
| 23 | 108 | 4.6 | 10 | 16 | 43 | |
| 24 | 29 | 4.6 | 14 | 9 | 48 | |
| 25 | -22 | 3.6 | 14 | 13 | 49 | |
| 26 | -15 | 5.6 | 12 | 15 | 48 | |
| | | 1.8 | | 9 | | (1) |
| 27 | 15 | 3.4 | 15 | 11 | 43 | (2) |
| 28 | 97 | 4.4 | 12 | 10 | 45 | |
| | | 2.2 | | 14 | | (1) |
| 29 | 62 | 4.4 | 23 | 8 | 46 | (2) |
| 30 | 30 | 4.6 | 14 | 11 | 43 | |
| 31 | 61 | 3.2 | 13 | 13 | 49 | |
| | | 1.8 | | 10 | | (1) |
| 32 | 31 | 2.4 | 15 | 9 | 45 | (2) |
| 33 | 31 | 3.0 | 13 | 12 | 46 | |
| | | 4.4 | | 5 | | (1) |
| 34 | -11 | 3.4 | 14 | 7 | 48 | (2) |
| 35 | 31 | 3.6 | 11 | 11 | 48 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 36 | 29 | 3.2 | 14 | 14 | 48 | |
| | | 1.2 | | 8 | | (1) |
| | | 0.2 | | 9 | | (1) |
| 37 | 29 | 0.4 | 14 | 6 | 45 | (2) |
| 38 | 34 | 1.8 | 7 | 10 | 42 | (1) |
| | | 0.6 | | 7 | | (2) |
| 39 | 32 | 1.2 | 16 | 7 | 44 | |
| 40 | 5 | 3.4 | 14 | 9 | 49 | |
| 41 | 14 | 2.4 | 10 | 13 | 46 | |
| 42 | 15 | 2.0 | 11 | 13 | 44 | |
| 43 | 56 | 1.6 | 15 | 12 | 47 | |
| 44 | 34 | 5.8 | 9 | 12 | 44 | |
| 45 | -8 | 2.8 | 15 | 12 | 47 | |
| 46 | 26 | 2.2 | 13 | 13 | 47 | |
| 47 | 20 | 4.2 | 12 | 11 | 48 | |
| 48 | -11 | 2.4 | 13 | 10 | 51 | |
| 49 | 25 | 3.0 | 7 | 18 | 40 | |
| | | 1.2 | | 8 | | (1) |
| | | 1.4 | | 5 | | (1) |
| 50 | 29 | 0.0 | 25 | 9 | 43 | (2) |
| 51 | 54 | 2.8 | 12 | 11 | 44 | |
| 52 | 20 | 3.6 | 14 | 14 | 44 | |
| 53 | 38 | 3.6 | 12 | 9 | 47 | |
| 54 | 9 | -0.8 | 14 | 15 | 46 | |
| 55 | 45 | 2.6 | 8 | 9 | 45 | |
| | | 5.4 | | 8 | | (1) |
| | | 0.2 | | 12 | | (1) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 56 | -35 | -0.2 | 27 | 7 | 45 | (2) |
| | | 1.0 | | 10 | | (1) |
| 57 | 40 | 2.0 | 18 | 7 | 46 | (2) |
| | | 2.0 | | 11 | | (1) |
| | | 0.8 | | 7 | | (1) |
| 58 | 99 | 4.4 | 25 | 8 | 45 | (2) |
| 59 | 30 | 3.6 | 15 | 13 | 47 | |
| 60 | 35 | 7.6 | 9 | 8 | 48 | |
| | | 4.1 | | 13 | | (1) |
| 61 | -24 | 1.4 | 24 | 12 | 47 | (2) |
| 62 | -25 | 2.4 | 11 | 10 | 48 | |
| 63 | -9 | 2.0 | 5 | 9 | 44 | |
| 64 | 25 | 1.8 | 10 | 12 | 42 | |
| 65 | -14 | 1.0 | 15 | 12 | 45 | |
| 66 | 27 | 1.0 | 7 | 8 | 44 | |
| 67 | 28 | 1.0 | 10 | 8 | 46 | |
| 68 | 28 | 0.6 | 8 | 8 | 46 | |
| 69 | 33 | 1.6 | 6 | 6 | 46 | |
| 70 | 5 | 0.8 | 12 | 10 | 48 | |
| 71 | 14 | 2.0 | 9 | 11 | 46 | |
| 72 | 48 | 3.6 | 13 | 10 | 49 | |
| | | 1.6 | | 10 | | (1) |
| 73 | 50 | 4.2 | 12 | 9 | 42 | (2) |
| | | 2.2 | | 11 | | (1) |
| 74 | 38 | 2.4 | 29 | 14 | 46 | (2) |
| 75 | 13 | 1.2 | 7 | 11 | 42 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 76 | 7 | 0.4 | 6 | 10 | 38 | |
| 77 | -4 | 4.0 | 14 | 8 | 44 | |
| | | 1.6 | | 9 | | (1) |
| 78 | 18 | 0.4 | 18 | 9 | 44 | (2) |
| 79 | -18 | -0.2 | 9 | 9 | 44 | |
| 80 | 3 | | 9 | | | (3) |
| 81 | 54 | -0.4 | 7 | 16 | 44 | |
| 82 | 54 | 2.6 | 15 | 15 | 44 | |
| 83 | 59 | 6.0 | 10 | 8 | 46 | |
| | | 2.2 | | 12 | | (1) |
| 84 | 13 | 2.8 | 20 | 10 | 44 | (2) |
| | | -0.4 | | 10 | | (1) |
| 85 | 94 | 4.0 | 22 | 13 | 43 | (2) |
| | | 0.8 | | 12 | | (1) |
| 86 | 52 | 2.6 | 31 | 15 | 43 | (2) |
| 87 | 15 | 1.4 | 13 | 13 | 46 | |
| | | 1.6 | | 8 | | (1) |
| 88 | 26 | 0.6 | 18 | 11 | 45 | (2) |
| 89 | 61 | 1.6 | 11 | 16 | 40 | |
| 90 | 32 | 6.0 | 12 | 7 | 45 | |
| 91 | -16 | 2.2 | 13 | 12 | 46 | |
| 92 | 26 | 4.0 | 10 | 9 | 47 | |
| 93 | -17 | 2.4 | 10 | 11 | 46 | |
| | | -1.4 | | 11 | | (1) |
| 94 | 52 | 2.6 | 19 | 11 | 43 | (2) |
| 95 | 27 | 1.0 | 16 | 9 | 50 | |
| | | 2.0 | | 7 | | (1) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 96 | 27 | 3.6 | 9 | 9 | 43 | (2) |
| | | 1.6 | | 9 | | (1) |
| 97 | 17 | 2.0 | 16 | 8 | 42 | (2) |
| | | -0.4 | | 8 | | (1) |
| 98 | 74 | 1.8 | 23 | 15 | 42 | (2) |
| 99 | 0 | 2.0 | 13 | 12 | 43 | |
| 100 | 30 | 4.4 | 10 | 11 | 42 | |
| | | 2.4 | | 9 | | (1) |
| 101 | -39 | 2.0 | 24 | 18 | 39 | (2) |
| 102 | 23 | 0.6 | 16 | 14 | 41 | |
| 103 | 29 | 1.6 | 14 | 11 | 44 | |
| | | 3.4 | | 9 | | (1) |
| 104 | 81 | 2.0 | 25 | 10 | 50 | (2) |
| | | 3.4 | | 10 | | (1) |
| | | 3.4 | | 8 | | (1) |
| 105 | 56 | -0.2 | 30 | 10 | 52 | (2) |
| | | 2.6 | | 9 | | (1) |
| 106 | -5 | 2.4 | 13 | 8 | 46 | (2) |
| | | 2.0 | | 12 | | (1) |
| 107 | 56 | 4.0 | 18 | 11 | 41 | (2) |
| 108 | 17 | 2.6 | 14 | 11 | 44 | |
| 109 | 62 | 8.2 | 10 | 11 | 43 | |
| | | 3.0 | | 9 | | (1) |
| 110 | -16 | 0.8 | 19 | 13 | 40 | (2) |
| 111 | 12 | 1.2 | 16 | 14 | 42 | |
| 112 | 7 | 1.8 | 12 | 10 | 44 | |
| | | -1.2 | | 7 | | (1) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 113 | 70 | 3.6 | 13 | 8 | 42 | (2) |
| 114 | 7 | 4.6 | 13 | 11 | 44 | |
| 115 | -6 | 6.2 | 8 | 9 | 43 | |
| | | 1.0 | | 10 | | (1) |
| 116 | 24 | 2.0 | 17 | 8 | 42 | (2) |
| | | 0.4 | | 8 | | (1) |
| 117 | 71 | 2.0 | 18 | 8 | 44 | (2) |
| 118 | 59 | 3.6 | 11 | 10 | 43 | |
| | | 4.4 | | 8 | | (1) |
| 119 | -38 | 3.8 | 18 | 11 | 44 | (2) |
| 120 | 55 | 1.8 | 13 | 14 | 43 | |
| | | 1.8 | | 10 | | (1) |
| 121 | -18 | 4.2 | 17 | 7 | 43 | (2) |
| 122 | 13 | 1.0 | 17 | 18 | 42 | |
| 123 | 24 | 3.6 | 9 | 10 | 41 | |
| 124 | 8 | 3.6 | 15 | 10 | 46 | |
| 125 | 29 | 1.2 | 12 | 14 | 44 | |
| 126 | 55 | 4.0 | 12 | 11 | 45 | |
| | | 5.6 | | 10 | | (1) |
| 127 | 94 | 4.0 | 18 | 10 | 43 | (2) |
| | | 0.0 | | 11 | | (1) |
| | | 0.4 | | 10 | | (1) |
| | | 2.0 | | 9 | | (1) |
| 128 | 63 | 2.4 | 37 | 9 | 41 | (2) |
| 129 | 30 | 1.6 | 16 | 13 | 44 | |
| 130 | 45 | 7.4 | 13 | 13 | 44 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 131 | -11 | 4.8 | 15 | 14 | 45 | |
| | | 1.2 | | 11 | | (1) |
| 132 | 30 | 0.0 | 22 | 10 | 46 | (2) |

RUN NUMBER FIVE   29 MARCH 1967

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 60 | 3.4 | | 7 | 41 | |
| 2 | 63 | 3.1 | 13 | 13 | 41 | |
| | | 3.4 | | 6 | | (1) |
| | | 3.3 | | 7 | | (1) |
| 3 | 48 | 0.3 | 18 | 6 | 40 | (2) |
| 4 | 30 | -0.1 | 10 | 8 | 42 | |
| 5 | 66 | 1.8 | 10 | 9 | 43 | |
| 6 | 44 | 4.2 | 13 | 12 | 44 | |
| | | 0.3 | | 9 | | (1) |
| 7 | 57 | 0.9 | 13 | 4 | 44 | (2) |
| 8 | 20 | 1.0 | 7 | 8 | 43 | |
| | | -1.0 | | 6 | | (1) |
| 9 | 52 | 3.0 | 12 | 10 | 39 | (2) |
| 10 | 16 | 2.6 | 8 | 10 | 37 | |
| 11 | 15 | 0.0 | 7 | 6 | 38 | |
| 12 | 40 | 1.0 | 9 | 5 | 42 | |
| 13 | 44 | 3.0 | 4 | 9 | 37 | |
| 14 | 40 | 1.0 | 8 | 5 | 40 | |
| 15 | 54 | 1.3 | 14 | 11 | 43 | |
| 16 | 92 | 3.9 | 8 | 11 | 40 | |
| | | 2.2 | | 10 | | (1) |
| | | -1.1 | | 8 | | (1) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 17 | 58 | 1.4 | 22 | 5 | 39 | (2) |
| 18 | 84 | 4.0 | 13 | 13 | 39 | |
| | | 3.1 | | 8 | | (1) |
| 19 | 20 | 4.1 | 15 | 3 | 43 | (2) |
| | | 1.3 | | 6 | | (1) |
| 20 | 60 | 2.3 | 17 | 10 | 44 | (2) |
| 21 | 97 | 2.3 | 13 | 18 | 39 | |
| | | 0.9 | | 7 | | (1) |
| 22 | 60 | 2.4 | 16 | 8 | 40 | (2) |
| 23 | 84 | 6.1 | 17 | 15 | 42 | |
| | | 2.3 | | 6 | | (1) |
| 24 | 56 | 2.8 | 13 | 8 | 41 | (2) |
| 25 | 39 | 1.5 | 8 | 7 | 37 | |
| 26 | 14 | 0.9 | 13 | 7 | 43 | |
| | | -0.2 | | 7 | | (1) |
| 27 | 41 | 2.7 | 14 | 11 | 39 | (2) |
| 28 | 34 | 1.6 | 15 | 7 | 47 | |
| 29 | 52 | 4.9 | 4 | 10 | 41 | |
| 30 | 29 | 0.0 | 5 | 5 | 41 | |
| 31 | 57 | 1.6 | 7 | 9 | 39 | |
| 32 | 61 | 5.2 | 4 | 5 | 38 | |
| 33 | 43 | | 9 | | | (3) |
| 34 | 73 | 4.9 | 7 | 15 | 39 | |
| 35 | 54 | | 8 | | | (3) |
| | | 1.0 | | 8 | | (1) |
| 36 | 36 | 1.4 | 12 | 5 | 42 | (2) |
| | | -3.8 | | 6 | | (1) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 37 | 49 | 3.8 | 15 | 10 | 41 | (2) |
| 38 | 117 | 7.8 | 9 | 16 | 34 | |
| 39 | 91 | 8.9 | 21 | 12 | 43 | |
| 40 | 49 | 1.0 | 13 | 8 | 48 | |
| 41 | 51 | 4.1 | 5 | 9 | 44 | |
| 42 | 38 | 2.1 | 12 | 13 | 43 | |
| | | 0.6 | | 12 | | (1) |
| 43 | 55 | 0.0 | 15 | 5 | 41 | (2) |
| 44 | 54 | 4.1 | 15 | 4 | 52 | |
| 45 | 67 | 5.0 | 4 | 15 | 41 | |
| 46 | 91 | 5.3 | 14 | 14 | 41 | |
| 47 | 73 | 3.2 | 13 | 16 | 38 | |
| 48 | 40 | 3.0 | 14 | 6 | 46 | |
| 49 | 36 | 3.2 | 8 | 10 | 44 | |
| | | 0.0 | | 11 | | (1) |
| 50 | 40 | 1.6 | 14 | 6 | 41 | (2) |
| 51 | 80 | 2.3 | 12 | 13 | 40 | |
| 52 | 49 | 2.4 | 6 | 7 | 39 | |
| 53 | 85 | 6.1 | 11 | 9 | 41 | |
| | | 1.3 | | 8 | | (1) |
| 54 | 53 | 2.6 | 19 | 14 | 38 | (2) |
| | | -0.5 | | 10 | | (1) |
| 55 | 68 | 4.4 | 16 | 5 | 39 | (2) |
| | | -1.0 | | 5 | | (1) |
| 56 | 54 | 2.5 | 17 | 9 | 42 | (2) |
| | | 3.3 | | 11 | | (1) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 57 | 32 | 4.1 | 20 | 8 | 43 | (2) |
| 58 | 54 | 4.0 | 10 | 12 | 41 | |
| 59 | 35 | -0.1 | 11 | 9 | 43 | |
| 60 | 61 | 3.1 | 7 | 10 | 40 | |
| 61 | 39 | 2.4 | 9 | 8 | 41 | |
| 62 | 35 | 1.2 | 10 | 8 | 43 | |
| 63 | 54 | 3.1 | 11 | 9 | 45 | |
| 64 | 53 | 7.6 | 7 | 10 | 42 | |
| 65 | 50 | 3.3 | 15 | 18 | 39 | |
| 66 | 92 | 2.6 | 15 | 4 | 50 | |
| | | 4.0 | | 16 | | (1) |
| 67 | 50 | 3.7 | 20 | 12 | 42 | (2) |
| | | 1.2 | | 8 | | (1) |
| 68 | 35 | 1.8 | 18 | 12 | 40 | (2) |
| 69 | -3 | 1.3 | 14 | 9 | 45 | |
| 70 | 30 | 1.2 | 10 | 9 | 46 | |
| 71 | 54 | 4.1 | 5 | 12 | 39 | |
| | | 1.0 | | 8 | | (1) |
| 72 | 62 | 7.1 | 18 | 8 | 41 | (2) |
| | | 1.0 | | 8 | | (1) |
| 73 | 92 | 5.0 | 14 | 12 | 38 | (2) |
| 74 | 61 | 3.2 | 16 | 15 | 39 | |
| | | 1.8 | | 7 | | (1) |
| 75 | 68 | 6.5 | 17 | 9 | 40 | (2) |
| 76 | 55 | 8.6 | 18 | 14 | 44 | |
| 77 | 66 | 2.8 | 12 | 19 | 37 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| | | -0.5 | | 6 | | (1) |
| 78 | 31 | 3.1 | 18 | 12 | 37 | (2) |
| 79 | 15 | 4.0 | 7 | 11 | 33 | |
| 80 | 54 | 1.0 | 10 | 4 | 39 | |
| 81 | 99 | 4.6 | 15 | 14 | 40 | |
| 82 | 62 | 2.3 | 17 | 17 | 40 | |
| | | -1.0 | | 11 | | (1) |
| 83 | 69 | 2.9 | 16 | 6 | 39 | (2) |
| 84 | 62 | 1.9 | 15 | 15 | 39 | |
| | | 1.4 | | 4 | | (1) |
| 85 | 115 | 3.8 | 16 | 12 | 39 | (2) |
| 86 | 47 | 3.5 | 14 | 12 | 41 | |
| | | 4.1 | | 4 | | (1) |
| 87 | 21 | -1.7 | 11 | 8 | 40 | (2) |
| 88 | 72 | 3.1 | 6 | 8 | 38 | |
| 89 | 45 | 5.0 | 15 | 12 | 41 | |
| | | 1.6 | | 12 | | (1) |
| 90 | 95 | 4.1 | 20 | 7 | 37 | (2) |
| 91 | 53 | 4.1 | 20 | 16 | 41 | |
| 92 | 47 | 2.2 | 13 | 15 | 39 | |
| | | 0.0 | | 5 | | (1) |
| | | 4.9 | | 6 | | (1) |
| 93 | 99 | 1.5 | 17 | 6 | 39 | (2) |
| | | -1.8 | | 12 | | (1) |
| 94 | 36 | 0.0 | 20 | 7 | 40 | (2) |
| | | 0.0 | | 7 | | (1) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 95 | 55 | 1.9 | 15 | 10 | 38 | (2) |
| | | -0.3 | | 9 | | (1) |
| 96 | 60 | 2.3 | 15 | 5 | 39 | (2) |
| 97 | 90 | 2.8 | 13 | 13 | 39 | |
| 98 | 32 | 2.3 | 7 | 6 | 40 | |
| | | 1.3 | | 9 | | (1) |
| 99 | 56 | 3.2 | 16 | 4 | 43 | (2) |
| 100 | 59 | 3.0 | 12 | 16 | 39 | |
| | | 2.1 | | 5 | | (1) |
| | | -1.1 | | 7 | | (1) |
| 101 | 48 | 1.0 | 18 | 3 | 42 | (2) |
| 102 | 41 | 4.9 | 7 | 8 | 41 | |
| 103 | 76 | 6.2 | 6 | 9 | 38 | |
| | | 5.7 | | 10 | | (1) |
| 104 | 56 | 2.8 | 22 | 10 | 40 | (2) |
| 105 | 37 | 2.6 | 14 | 11 | 43 | |

RUN NUMBER SIX 31 MARCH 1967

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 1 | 47 | 9.0 | 13 | 13 | 39 | |
| | | 8.1 | | 13 | | (1) |
| 2 | 8 | 1.0 | 18 | 8 | 36 | (2) |
| 3 | 54 | 2.6 | 22 | 14 | 44 | |
| 4 | 65 | 4.3 | 10 | 13 | 41 | |
| 5 | 71 | 8.8 | 15 | 9 | 47 | |
| 6 | 35 | 8.6 | 16 | 16 | 47 | |
| 7 | 69 | 10.2 | 12 | 14 | 45 | |
| 8 | 13 | 7.7 | 13 | 13 | 45 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 9 | 60 | 7.3 | 10 | 12 | 43 | |
| 10 | 88 | 14.0 | 14 | 13 | 44 | |
| 11 | 11 | 7.9 | 16 | 15 | 45 | |
| 12 | 43 | 8.8 | 12 | 15 | 42 | |
| | | 1.9 | | 14 | | (1) |
| 13 | -23 | 1.2 | 22 | 10 | 40 | (2) |
| 14 | -2 | 3.0 | 15 | 14 | 41 | |
| 15 | 84 | 5.1 | 14 | 13 | 42 | |
| 16 | 69 | 3.3 | 14 | 15 | 41 | |
| 17 | 63 | 5.2 | 15 | 14 | 42 | |
| | | 1.4 | | 13 | | (1) |
| 18 | 9 | 2.6 | 26 | 9 | 46 | (2) |
| | | 2.2 | | 12 | | (1) |
| 19 | 23 | 2.5 | 13 | 7 | 40 | (2) |
| 20 | 35 | 5.7 | 13 | 11 | 42 | |
| | | 3.3 | | 13 | | (1) |
| 21 | 74 | 4.2 | 28 | 15 | 42 | (2) |
| 22 | 59 | 7.2 | 13 | 13 | 42 | |
| 23 | 110 | 9.8 | 14 | 15 | 41 | |
| 24 | 91 | 11.2 | 15 | 15 | 40 | |
| 25 | -15 | 4.3 | 21 | 15 | 46 | |
| 26 | 34 | 5.4 | 12 | 17 | 41 | |
| 27 | 20 | 7.1 | 13 | 11 | 43 | |
| | | 1.7 | | 9 | | (1) |
| 28 | 23 | 4.1 | 20 | 15 | 39 | (2) |
| 29 | 57 | 5.1 | 15 | 12 | 42 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 30 | 52 | 7.7 | 15 | 14 | 43 | |
| 31 | 52 | 7.8 | 15 | 15 | 43 | |
| | | 5.5 | | 12 | | (1) |
| 32 | 70 | 5.9 | 22 | 11 | 42 | (2) |
| | | 5.5 | | 11 | | (1) |
| 33 | 53 | 5.6 | 31 | 21 | 41 | (2) |
| 34 | 41 | 7.9 | 16 | 14 | 43 | |
| 35 | 56 | 7.3 | 12 | 11 | 44 | |
| | | 2.9 | | 13 | | (1) |
| 36 | 0 | 3.3 | 22 | 11 | 42 | (2) |
| 37 | -2 | 2.1 | 13 | 10 | 45 | |
| 38 | 27 | 2.5 | 12 | 13 | 44 | |
| | | 2.0 | | 12 | | (1) |
| 39 | 70 | 6.1 | 22 | 10 | 44 | (2) |
| 40 | 37 | 6.1 | 13 | 12 | 45 | |
| 41 | 7 | 1.8 | 16 | 20 | 41 | |
| 42 | 123 | 8.2 | 25 | 14 | 42 | |
| 43 | 109 | 10.9 | 15 | 15 | 42 | |
| 44 | 63 | 14.3 | 14 | 16 | 40 | |
| 45 | 63 | 15.0 | 15 | 14 | 41 | |
| 46 | 23 | 12.1 | 17 | 16 | 42 | |
| 47 | 12 | 4.0 | 14 | 16 | 40 | |
| 48 | 109 | 11.2 | 12 | 13 | 39 | |
| 49 | 41 | 7.5 | 19 | 15 | 43 | |
| | | 1.1 | | 9 | | (1) |
| 50 | 2 | 3.6 | 18 | 9 | 43 | (2) |
| | | 1.1 | | 9 | | (1) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 51 | 0 | 2.4 | 19 | 10 | 43 | (2) |
| 52 | 30 | 2.1 | 15 | 13 | 45 | |
| | | 1.0 | | 12 | | (1) |
| 53 | 58 | 6.2 | 17 | 10 | 40 | (2) |
| 54 | 109 | 6.1 | 12 | 11 | 41 | |
| 55 | 86 | 9.2 | 14 | 13 | 42 | |
| 56 | 84 | 10.9 | 13 | 13 | 42 | |
| 57 | 15 | 7.2 | 16 | 15 | 43 | |
| | | 6.6 | | 12 | | (1) |
| 58 | 45 | 4.2 | 22 | 12 | 41 | (2) |
| 59 | 97 | 11.7 | 14 | 11 | 44 | |
| 60 | 12 | 9.8 | 17 | 16 | 45 | |
| 61 | 68 | 8.6 | 13 | 17 | 41 | |
| 62 | 37 | 6.9 | 16 | 13 | 44 | |
| 63 | 30 | 4.9 | 14 | 15 | 43 | |
| | | 4.0 | | 7 | | (1) |
| 64 | 107 | 10.0 | 15 | 10 | 41 | (2) |
| 65 | 51 | 11.3 | 15 | 13 | 43 | |
| 66 | 22 | 7.2 | 13 | 13 | 43 | |
| | | 5.1 | | 12 | | (1) |
| 67 | 30 | 1.3 | 26 | 14 | 43 | (2) |
| 68 | 71 | 2.0 | 12 | 15 | 40 | |
| 69 | 51 | 4.2 | 13 | 10 | 43 | |
| | | 4.1 | | 9 | | (1) |
| 70 | 25 | 4.1 | 16 | 7 | 43 | (2) |
| 71 | 8 | 3.2 | 11 | 10 | 44 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 72 | 36 | 4.3 | 14 | 13 | 45 | |
| 73 | 18 | 2.0 | 13 | 16 | 42 | |
| 74 | 56 | 3.2 | 15 | 18 | 39 | |
| 75 | 88 | 8.8 | 12 | 11 | 40 | |
| 76 | 9 | 3.6 | 20 | 16 | 44 | |
| 77 | 10 | 3.8 | 20 | 18 | 46 | |
| 78 | 67 | 2.7 | 11 | 17 | 40 | |
| 79 | 116 | 10.6 | 12 | 12 | 40 | |
| | | 5.0 | | 13 | | (1) |
| | | 0.8 | | 9 | | (1) |
| 80 | 51 | 3.6 | 37 | 13 | 42 | (2) |
| 81 | 131 | 8.1 | 10 | 13 | 39 | |
| 82 | 108 | 12.1 | 15 | 13 | 41 | |
| 83 | 107 | 16.1 | 15 | 15 | 41 | |
| 84 | -6 | 8.2 | 15 | 15 | 41 | |
| 85 | 39 | 10.0 | 16 | 14 | 42 | |
| | | 4.9 | | 14 | | (1) |
| | | 2.4 | | 8 | | (1) |
| 86 | 84 | 7.4 | 29 | 11 | 39 | (2) |
| 87 | 9 | 4.9 | 15 | 11 | 43 | |
| 88 | 66 | 7.1 | 14 | 14 | 43 | |
| 89 | 87 | 8.1 | 11 | 13 | 41 | |
| 90 | 34 | 6.2 | 20 | 15 | 46 | |
| 91 | 42 | 5.0 | 10 | 15 | 41 | |
| 92 | 31 | 4.3 | 10 | 12 | 39 | |
| 93 | 8 | 3.2 | 19 | 16 | 42 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 94 | 30 | 3.3 | 11 | 14 | 39 | |
| 95 | 2 | 1.9 | 13 | 9 | 43 | |
| 96 | 35 | 4.3 | 11 | 13 | 41 | |
| 97 | 70 | 5.2 | 12 | 11 | 42 | |
| | | 3.1 | | 10 | | (1) |
| 98 | 31 | 0.6 | 17 | 9 | 40 | (2) |
| 99 | 22 | 2.8 | 12 | 11 | 41 | |
| 100 | 30 | 5.1 | 14 | 15 | 40 | |
| 101 | 68 | 7.1 | 11 | 14 | 37 | |
| 102 | 112 | 13.4 | 15 | 14 | 38 | |
| 103 | 143 | 18.8 | 15 | 15 | 38 | |
| 104 | 75 | 17.6 | 17 | 14 | 41 | |
| | | 7.4 | | 17 | | (1) |
| 105 | 70 | 9.5 | 31 | 18 | 37 | (2) |
| 106 | 141 | 16.6 | 15 | 13 | 39 | |
| 107 | 66 | 16.1 | 17 | 14 | 42 | |
| 108 | -5 | 9.0 | 15 | 16 | 41 | |
| 109 | 64 | 11.6 | 11 | 15 | 37 | |
| 110 | 77 | 13.9 | 20 | 15 | 42 | |
| 111 | 18 | 9.0 | 13 | 14 | 41 | |
| 112 | 31 | 6.9 | 8 | 9 | 40 | |
| 113 | 108 | 9.9 | 10 | 13 | 37 | |
| 114 | 93 | 14.0 | 17 | 14 | 40 | |
| 115 | 82 | 15.0 | 14 | 14 | 40 | |
| 116 | 35 | 11.2 | 17 | 16 | 41 | |
| 117 | 48 | 10.8 | 12 | 12 | 40 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 118 | 37 | 8.0 | 13 | 15 | 38 | |
| 119 | 37 | 7.2 | 15 | 15 | 38 | |
| 120 | 30 | 5.0 | 18 | 15 | 41 | |
| 121 | 11 | 2.3 | 12 | 15 | 38 | |
| | | 1.1 | | 10 | | (1) |
| 122 | 68 | 6.1 | 20 | 8 | 40 | (2) |
| 123 | 66 | 7.0 | 16 | 15 | 41 | |
| 124 | -9 | 3.1 | 14 | 13 | 42 | |
| 125 | 59 | 1.5 | 14 | 15 | 41 | |
| 126 | 49 | 3.6 | 11 | 12 | 40 | |
| | | 2.8 | | 9 | | (1) |
| | | 1.8 | | 10 | | (1) |
| 127 | 60 | 6.7 | 26 | 10 | 37 | (2) |
| 128 | 36 | 7.7 | 15 | 11 | 41 | |
| 129 | 108 | 12.3 | 14 | 16 | 39 | |
| 130 | 100 | 14.0 | 16 | 16 | 39 | |
| 131 | 100 | 16.6 | 16 | 13 | 42 | |
| 132 | 34 | 12.6 | 14 | 15 | 41 | |
| 133 | 34 | 7.0 | 15 | 14 | 42 | |
| 134 | 37 | 6.9 | 13 | 16 | 39 | |
| 135 | 18 | 7.1 | 13 | 11 | 39 | |
| | | 1.9 | | 13 | | (1) |
| 136 | 107 | 7.4 | 27 | 12 | 41 | (2) |
| 137 | 29 | 8.1 | 12 | 11 | 42 | |
| 138 | -8 | -0.4 | 14 | 11 | 45 | |
| | | 4.8 | | 9 | | (1) |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 139 | 68 | 5.2 | 16 | 15 | 37 | (2) |
| 140 | 106 | 10.8 | 14 | 12 | 38 | |
| 141 | 111 | 15.0 | 15 | 14 | 39 | |
| 142 | 27 | 9.3 | 17 | 15 | 41 | |
| 143 | 48 | 8.9 | 12 | 15 | 38 | |
| 144 | 23 | 4.1 | 16 | 16 | 38 | |
| 145 | 51 | 6.2 | 11 | 19 | 40 | |
| 146 | 62 | 9.1 | 17 | 17 | 40 | |
| 147 | 159 | 14.1 | 10 | 14 | 36 | |
| 148 | 137 | 17.7 | 13 | 13 | 36 | |
| 149 | 57 | 13.6 | 19 | 14 | 41 | |
| 150 | 7 | 5.6 | 22 | 17 | 46 | |
| 151 | -10 | 6.7 | 7 | 14 | 39 | |
| | | 1.3 | | 8 | | (1) |
| 152 | 89 | 7.4 | 21 | 13 | 39 | (2) |
| 153 | 126 | 13.6 | 10 | 13 | 36 | |
| 154 | 62 | 11.2 | 15 | 13 | 40 | |
| 155 | 17 | 6.2 | 15 | 15 | 38 | |
| 156 | 100 | 11.1 | 16 | 16 | 38 | |
| 157 | 124 | 12.1 | 14 | 14 | 38 | |
| | | 8.9 | | 14 | | (1) |
| | | 6.6 | | 8 | | (1) |
| 158 | 25 | 3.2 | 33 | 14 | 35 | (2) |
| 159 | 45 | 4.1 | 17 | 13 | 39 | |
| 160 | -10 | 3.4 | 15 | 14 | 40 | |
| 161 | 49 | 6.1 | 16 | 16 | 40 | |

| RN | RV | CE | RI | WI | TT | |
|---|---|---|---|---|---|---|
| 162 | 87 | 6.6 | 12 | 13 | 39 | |
| 163 | 80 | 6.2 | 17 | 17 | 39 | |
| 164 | 72 | 10.2 | 14 | 11 | 42 | |
| 165 | 15 | 4.6 | 12 | 15 | 39 | |
| 166 | 8 | 1.0 | 17 | 14 | 42 | |
| | | 1.8 | | 5 | | (1) |
| 167 | 100 | 8.2 | 17 | 12 | 42 | (2) |
| 168 | 99 | 11.6 | 13 | 15 | 40 | |
| 169 | 58 | 10.2 | 12 | 14 | 38 | |
| 170 | 97 | 9.5 | 16 | 17 | 39 | |
| 171 | 48 | 11.0 | 15 | 12 | 40 | |
| 172 | 52 | 6.3 | 14 | 15 | 39 | |
| 173 | 88 | 12.1 | 15 | 16 | 38 | |
| 174 | 65 | 10.3 | 15 | 17 | 36 | |
| 175 | 74 | 13.3 | 16 | 14 | 38 | |
| 176 | -22 | 4.9 | 19 | 12 | 45 | |
| 177 | 77 | 4.0 | 16 | 22 | 39 | |
| 178 | 100 | 10.0 | 12 | 13 | 38 | |
| 179 | 47 | 9.3 | 17 | 14 | 41 | |
| 180 | 48 | 6.8 | 14 | 17 | 38 | |

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13. ABSTRACT

Six sets of field measurements of runup resulting from both wind waves and swell were made on a uniform sand beach. Waves were recorded simultaneously directly offshore at a point outside the surf zone. Each individual runup was correlated with a specific wave, using a travel-time plot. Runup occurrences were always found to be fewer in number than wave occurrences, particularly when wind waves were present. Large variations in the runup resulting from waves of a given height were found to exist. These variations in height and ratio of runup to waves were caused in large part by the interaction of successive foam lines. Interaction occurred in the form of retardation by backwash of preceding waves, overtaking by a following foam line, and overriding by a small unbroken wave. It is concluded that the complicated nature of runup resulting from ordinary sea and swell makes it difficult to predict runup accurately from laboratory studies.

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